TECHNICAL REPORT
NATICK/TR-92/007

AD ______________

USER EVALUATION OF LASER BALLISTIC SUN, WIND AND DUST GOGGLE LENSES (DYE TECHNOLOGY)

By
B. Jezior
C. L. Blackwell
L. L. Lesher*
V. Shearer*
L. Plante*
K. Burke*
B. Patterson*

*GEO-CENTERS, INC.
Newton Centre, MA 02159

November 1991

FINAL REPORT
September 1990 - September 1991

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

Prepared for
UNITED STATES ARMY NATICK
RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
NATICK, MASSACHUSETTS 01760-5040

SOLDIER SCIENCE DIRECTORATE

DISCLAIMERS

The findings contained in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of trade names in this report does not constitute an official endorsement or approval of the use of such items.

DESTRUCTION NOTICE

For Classified Documents:

Follow the procedures in DoD 5200.22-M, Industrial Security Manual, Section II-19 or DoD 5200.1-R, Information Security Program Regulation, Chapter IX.

For Unclassified/Limited Distribution Documents:

Destroy by any method that prevents disclosure of contents or reconstruction of the document.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
November 1991

3. REPORT TYPE AND DATES COVERED
FINAL SEPT 90 TO SEPT 91

4. TITLE AND SUBTITLE
User Evaluation of Laser Ballistic Sun, Wind and Dust Goggle Lenses (Dye Technology)

5. FUNDING NUMBERS
PR 64713
TA DL4095
AGGCODE TSK1767

6. AUTHOR(S)
Jezior, B.; Blackwell, C.L.; Lesher, L.L.*; Shearer, V.*; Plante, L.*; Burke, K.*; Patterson, B.*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Natick Research, Development and Engineering Center
Kansas Street
Natick, Massachusetts 01760-5020

8. PERFORMING ORGANIZATION REPORT NUMBER
NATICK/TR-92/007

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
* Professional Affiliations: GEO-CENTERS, INC., Newton Centre, MA 02159

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Prompted by a Product Improvement Program aimed at providing soldiers eye protection equal to that of the Ballistic Laser Protective Spectacles (BLPS), Natick Research, Development and Engineering Center recently field tested four experimental laser ballistic lenses in the Sun, Wind, and Dust Goggle. All lenses used dye absorber technology.

Field testing with Armor and Infantry military personnel resulted in data collected from more than 300 soldiers on over 80 variables. The tests included typical military operational tasks. The soldiers also wore the lenses during field training exercises and were surveyed about the lenses' effects on mission performance. The Farnsworth-Munsell 100-Hue Test, a laboratory test which examines the effects of the lenses on color perception, was also conducted in both simulated daylight and reduced visibility conditions.

Farnsworth-Munsell test results showed that performance was not seriously degraded by any lens in daylight illumination levels. In reduced visibility conditions there was impairment, and the degree of impairment was relatively consistent with what was expected from the respective lenses' transmittance levels

14. SUBJECT TERMS BALLISTIC GOGGLES SUN WIND AND DUST

GOGGLES	COLOR PERCEPTION	LASER PROTECTION
LENSES	DAYLIGHT	BALLISTIC LASER PROTECTIVE
DYE TECHNOLOGY	VISIBILITY	GOGGLES

15. NUMBER OF PAGES
92

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

BLOCK 13. ABSTRACT (continued)
and specific lines of protection. There were also some negative mission performance issues raised that were more a function of goggle wear than lens performance.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

From September, 1990 to September, 1991, U.S. Army Natick, Research Development and Engineering Center undertook a field testing program of the ballistic/laser protective goggle to determine its effects on soldier performance. The program was part of task #DL4095 under project #64713 "Sun, Wind & Dust Goggle Laser Protective Lenses".

Citation of trade names in this report does not constitute an official endorsement or approval of the use of such items.

The dedication and sheer hard work involved in this project will become apparent to the readers as they wend their way through this report. There were many people involved in this enormous effort, and they all deserve recognition and heartfelt appreciation. It is through their efforts that our soldiers will now be better protected from laser threat, and the groundwork has been laid for future field testing of laser ballistic protective eyewear.

The person who is the linchpin to the whole effort is the project officer, Wayne Burkhardt of Natick's Individual Protection Directorate, who kept the test people who supported him informed and on track, and who was an inspiration to us all. He left no doubt in anyone's mind that he truly was committed to providing soldiers with the eye protection that they need.

Two others who bear special mention are Ms. Cynthia Blackwell and Ms. Vicki Shearer. Ms. Blackwell was responsible for the field testing conducted at Ft. Polk, Louisiana. There were a number of tasks that were executed there in blistering August heat and inside of tracked vehicles. Her able guidance and "can-do" attitude helped test personnel as well as the test subjects to overlook the unpleasant environment and get the mission accomplished - and it was accomplished admirably.

Ms. Shearer was in charge of the Farnsworth-Munsell 100-Hue Test. She found subjects (volunteers whom we could pay nothing), set up test schedules, and conducted much of the testing herself. She also trained others on how to conduct the testing, and showed infinite patience in all the rescheduling and other testing snarls that are inevitable in a test with such scope.

This report would probably not have been accomplished without Ms. Shearer's efforts as well. She drafted many of the sections, made many of the editorial changes, composed many of the graphics, and completed the tedious work required for Table of Contents, writing the abstract, getting the appendices assembled and so on.

Also worthy of many thanks is our staff statistician, Mr. Larry Lesher. He played an instrumental role in test design, as well as performed countless statistical analyses on the volume of data required for this project.

We are also very grateful to Dr. Bruce Gillers, an ophthalmologist who volunteered his time to help us. He critiqued our report drafts, and helped with the interpretation of statistical findings.

Space limitations prevent detailed descriptions of the many, many others who contributed to the work accomplished here. However, special thanks are in order for Lisa Richards, Karen Burke, Laurie Plante and Bonnie Patterson.

USER EVALUATION OF LASER BALLISTIC SUN, WIND AND DUST GOGGLE LENSES (DYE TECHNOLOGY)

INTRODUCTION

Natick Research, Development, and Engineering Center (Natick) recently undertook a Product Improvement Program (PIP) for the standard issue ballistic Sun, Wind, and Dust (SWD) Goggles for which the U.S. Army Armor School is the proponent. The improvement was concerned solely with adding laser protection to the ballistic goggle so that soldiers whose missions require using the goggle would have the same protection afforded by the Ballistic Laser Protective Spectacle (BLPS). The need for laser protection exists not only because of enemy weaponry but also because of the laser emissions from some sophisticated equipment of the U.S. Armed Forces, such as rangefinders and target designators.

The problem with providing laser protection is that the more levels of protection (also called lines or lambdas) that are in a lens, the harder it is for the wearer to see, because each additional line reduces the amount of light transmitted through the lens. Also, the various lines can significantly distort certain colors. This means there are some trade-offs to be made in protection versus mission performance.

The PIP program has several candidate lenses under consideration that include dye and reflective laser protective technologies. Two of the dye technology lenses were procured in limited numbers for quick fielding because of the urgent need for protection. They were both American Optical lenses and were procured on the basis of laboratory and technical testing data, as well as some field testing conducted in the aviation community.

One of the lenses procured has three laser lines of protection and was assumed to be suitable for daytime wear; the other, with two lines, was assumed to be suitable in reduced visibility conditions as well as daylight.

There is a sore need for field data on these laser lenses in terms of the effects they have in an operational environment. In fact, there is a need for field data on laser lenses in general. The body of data that does exist relates mainly to prototype lenses and much of that is classified, which, of course, limits the availability of the data.

There were some unclassified field data from the aviation community that were obtained in testing. Included were two of the candidate lenses (in pilot visors) from one of the manufacturers whose lenses were procured for this PIP program. The number of users of these lenses, however, was small, and the aviation

environment and mission are quite different from that of the primary goggle user, the armored combat soldier. (See Appendix A for a summary of the aviation data.)

The Individual Protection Directorate of Natick therefore asked Natick's Behavioral Sciences Division, Soldier Science Directorate, to conduct some field (user) tests of the lenses. This report describes those tests and findings.

FIELD TESTING APPROACH

There was little need for field testing the SWD goggle per se; nothing about it or its logistic support changed with the addition of laser protection to the ballistic lens.

The development of the standard goggle to type classification created a body of data, which speaks to the variables of durability, comfort, fit, etc.[1-4] While there was, of course, interest in collecting some data on those types of variables, the primary concerns were the visual effects of using the laser/ballistic lenses. In any event, a program is underway to design and develop a new ballistic/laser SWD goggle (the Advanced Wind and Dust Goggle). Prototypes developed under the program will be subjected to all human factors and technical testing normally associated with goggles.

Field testing the lenses' laser protective capabilities was also no issue; laser protection levels were determined through technical testing.

The basic questions we wanted to answer through field testing were:

(1) Is the soldier having a problem seeing through the lenses to the extent that they seriously impact on mission performance?
(2) Are the lenses distorting color in some manner that seriously impacts mission performance and may present a hazard?

The testing was shaped by a number of considerations. In addition to the typical constraints imposed by dollars, manpower, a severe shortage of some of the test lenses, and a very short lead time, we also had to construct new tests. There was no established methodology for testing the issues that concerned us. One of the reasons for the lack of a methodology is the difficulty of testing visual issues in a field situation. Not only is there the problem of the limited control that can be maintained in the field for any given testing scenario, but the additional problems posed by inability to control the independent variables of light levels and color.

To overcome the difficulty of testing imposed by the field environment, the approach was to have many soldiers evaluate the lenses in a wide variety of military tasks in different levels of illumination. This "shot-gun" approach presumably would surface any critical problems. Moreover, if the body of test data were consistent with the laboratory data and with what is known of perceptual processes, some measure of confidence in the soldier's performance levels wearing the lenses would be justified.

Several rating scales and measures were used across the test tasks. There was no way to be sure of what to expect in some cases, much less the best way to measure the responses. For instance, rating on a traditional verbal rating scale the ability to see an object would be inappropriate if a lens completely obliterated the soldier's perception, as the scale's lowest anchor would indicate only that the object is very difficult to see. There is a critical difference between seeing something with great difficulty and not seeing it at all.

The test tasks we developed to answer our questions took much of their substance from the Armor School's criteria on specific issues they wanted addressed as proponent for the lenses. Among these were whether there are significant differences among lens candidates in the ability of the crew to acquire targets, navigate, drive, or operate in their vehicle compartments (e.g., detect warning/hazard lights).

We also conducted one laboratory test. Since there were no laboratory data available for color distortion the lenses might cause, we opted to conduct the Farnsworth-Munsell 100-Hue Test.[5-6] Some visual acuity and depth perception data were available for similar laser protective devices, which did not indicate any unexpected visual impairments for those factors (see Appendix A).

TESTING SITES/TIME PERIOD/SCOPE

The sources for user data on the lenses were:

1. The Farnsworth-Munsell 100-Hue Test
2. Target acquisition (dismounted) tasks
3. Map readability tasks
4. Static vehicle compatibility assessments
5. Blackout lighting (cat's eyes) tasks
6. Use in tracked vehicle operation on a 3.5k tank trail
7. Use during a field exercise (nonintrusive)

The testing was conducted from April-October 1990 at three sites: Natick, MA; Ft. Devens, MA; and Ft. Polk, LA. The bulk of the field data came from the 1st Brigade, 5th Infantry Division (Mechanized), at Ft. Polk. This unit agreed to support goggle testing with minimal interference by researchers during

field training in August, 1991.* Crewmen from this brigade provided the data for target acquisition, static compatibility, operational, and blackout lighting tests. Ft. Devens was the site for two of the data sets; members of the 10th Special Forces performed the map readability tasks, and a reserve armor unit, Delta Troop, 5th Armored Cavalry, used the goggles during a weekend training exercise. The Farnsworth-Munsell 100-Hue Test was conducted at Natick with military and civilian personnel.

LENS DESCRIPTION/USE IN TESTING

Out of the many candidate lenses, nine were chosen to test: five from American Optical (AO) and and four from Gentex (G). Two of these lenses were procured under the PIP program. Both manufacturers provided lenses with one, two, and three lines of protection. American Optical provided two versions of a lens with three lines of protection that varied in tint; one was brown, the other purple. Both manufacturers employed a dye absorber technology for all lenses. The levels, tints, and nomenclature of the lenses are shown in Table 1.

TABLE 1
DESCRIPTION OF TEST LENSES

Level of Protection	American Optical	Nomenclature	Gentex	Nomenclature
Lambda 3	yellow	AO3	yellow-green	G3
Lambda 1,2	yellow-pink	AO12	yellow-pink	G12
Lambda 2,3	green	AO23	yellow-green	G23
Lambda 1,2,3	brown	AO123(B)	yellow-green	G123
Lambda 1,2,3	purple	AO123(P)	--	

Visual transmittance and color perception are degraded differently by the various lenses but, in general, the more levels of laser protection in the visible spectrum, the more transmittance is reduced. More specifically, the transmittances of all the lenses except the lenses with three lines of protection are better than the standard issue SWD goggle's tinted (sunglass) lens, while the tranmittances of the lenses with the three lines are similar to that standard sunglass lens, as indicated in Table 2.

The specific wavelengths affected by the lines of protection in the lenses evaluated are:

Lambda 3 = 1064 microns (infrared; not visible)
Lambda 2 = 694 microns (orange-red)
Lambda 1 = 532 microns (green)

----

*In conjunction with some of these tests, Major Robert Matthews from Combined Arms Combat Development Activity was testing a laser protective goggle from the United Kingdom.

TABLE 2

LENS TECHNICAL TESTS:

GOGGLE LENS	L1	OPTICAL DENSITY* L2	L3	VISUAL TRANSMITTANCE: DAYTIME (PHOTOPIC) VT%	VISUAL TRANSMITTANCE: NIGHTTIME (SCOTOPIC) VT%	BALLISTICS VELOCITY** FT/SEC (17 GR) V(50)	(17 GR) (V0)	(5.8 GR) V(50)	(5.8 GR) V(0)	CRACKING***
AO										
3	-	-	4.8 (4.9)	67.5	58.4	<623	550	-	-	
12	4.5	>5 (3.7)	-	16.2	14.6	<728	625	-	-	
23	-	>5 (4.2)	4.6 (5.0)	44.1	47.9	>624	575	-	-	W/17 GR
123B	3.9	>5 (4.4)	4.8 (4.8)	13.7	10.0	693	575	-	-	W/17 GR
123P	4.2	5.2	4.2	7.3	10.0	665	578	-	-	
GENTEX										
3	-	-	>5 (4.0)	49.5	38.78	715	650	-	-	
12	3.0	3.5 (0.4)	-	27.4	18.25	652	525	-	-	W/17 GR
23	-	4.3 (2.3)	>5 (4.0)	29.2	23.48	721	625	-	-	
123	3.7	4.1 (1.9)	>5 (4.2)	16.9	6.48	>732	625	866	750	W/17 GR

----

* Optical densities in ( ) were obtained from USAEHA

** V(50) = 50% chance of failure; V(0) = no chance of failure

*** All cracking problems occurred around or above V(50), No cracking observed near V(0) values

While the wavelengths that are affected are known, the effects of the interactions created by the affected wavelengths, the color tint of any particular lens, and the environmental backgrounds are not known and are beyond the scope of our testing.

As the number of lenses available for testing was limited, none could be provided to any user for long-term use. There were also restrictions on the number of types of lenses that could be included in any given test because of mission requirements, limited access time to subjects, and other pragmatic issues. For instance, some of the candidate lenses were in such short supply they could not be used in test situations (e.g., field exercises) that could easily result in loss or breakage. Moreover, one of the candidates, AO123(P), was not available until most of the testing was completed, and again very few were available. These considerations meant that the candidates could not be assessed in a methodical, all-encompassing manner.

Whenever testing had to be limited to a few candidates, the primary concern was to include at least the lenses that had been procured for the limited fielding, i.e., AO23, and AO123(B). Also, technical tests of the Gentex lenses showed while they met the specifications for laser protection, they did not meet some of the other technical specifications; as a result Gentex lenses were excluded from all test situations except for the Farnsworth-Munsell 100-Hue test.

DATA HANDLING/ANALYSIS

Statistics used in this report to describe the data are the number of responses (N), the mean or average (X), and the standard deviation (SD). The SD is an indication of how diverse the responses are: the higher the SD, the less similar the responses.

A chi-square test was used on dichotomous (e.g., yes/no) data to see if groups differed. Analyses of variance (ANOVAs and MANOVAs) were conducted on quantitative data to determine differences between two or more groups. When ANOVA or MANOVA findings were significant, the post hoc technique used to determine differences in group means was the Student-Newman-Keuls (SNK). A test for homogeneity of proportions was the technique used after a chi square analysis showed significance to test for significant differences when comparing more than two groups. The minimum criterion level for determining significance for any test was .05. This criterion states that 95 times out of 100 the observed difference is a true difference and not chance occurrence.

We conducted inferential tests whenever we felt they were appropriate. There were some data sets that would not justify the tests' use, the most common reason being a small sample size. In such cases only descriptive statistics were calculated.

TECHNICAL TESTING

Laboratory/technical testing showed that the laser protective lenses meet the MIL-G-43914 standard for impact resistance and ultraviolet visual transmittance (VT) just as the standard lenses do. Table 2 contains those data as well as the optical density values (heights for particular wavelengths).[7] Note that V(50) is indicative of a velocity at which there is a 50 percent chance of failure, and V(0) indicates a velocity at which there is one-hundred percent chance of success (no penetration of the lenses). V(0) values are especially important when dealing with eyewear due to the sensitive nature of the eye.

FARNSWORTH-MUNSELL 100-HUE TEST

The Farnsworth-Munsell 100-Hue test is sensitive to minor effects on color perception, and as such can be used to predict performance on color-dependent tasks. It is also sensitive to changes in illumination level.

For those unfamiliar with the test, a short version of the manual describing its composition, administration, scoring and interpretation is in Appendix B.[6]

Objective

To determine how each of the candidate lenses affects color perception.

Test Procedures

A total of 74 Natick personnel (39 males, 35 females) were test subjects; 12 of the males were military. The age range was 19 to 35, the average was 30.

The test lenses were all the American Optical and Gentex lenses described in Table 1 except AO123(P). Each subject was randomly assigned to one of four test conditions: 1) dusk illumination and testing all AO lenses, 2) dusk illumination and testing all Gentex lenses, 3) daylight illumination and testing all AO lenses, and 4) daylight illumination and testing all Gentex lenses. Lens order presentation was also randomized, but each subject first performed the test in a naked eye condition (baseline). Thus, each subject performed the Farnsworth-Munsell task five times. Subjects were screened with the Dvorine Pseudo-Isochromatic Plates to ensure that there were no color defectives and self reportsindicated normal or corrected-to-normal vision. Subjects assigned to the dusk conditions dark-adapted for 15 minutes.

Subjects sat at a table in the middle of a conference room. The daylight condition was simulated with overhead fluorescent lighting, and the dusk was simulated by two small fluorescent lamps used at the sides of the rooms with the light directed away from the subjects and at the ceiling. There was also one incandescent lamp used which was directed at a white screen and placed approximately 15 feet away from the subject. The daylight condition was set at 75 foot-candles and the dusk condition 0.5 (which is a deep dusk level); readings were taken at the testing table with a Simpson Illumination Level Meter.

Results

Figures 1-4 show the test results for all lenses and both conditions that were scored and plotted on a chromaticity circle according to test manual instructions (Appendix B). The average total error score (TES) and SD for each lens is indicated under

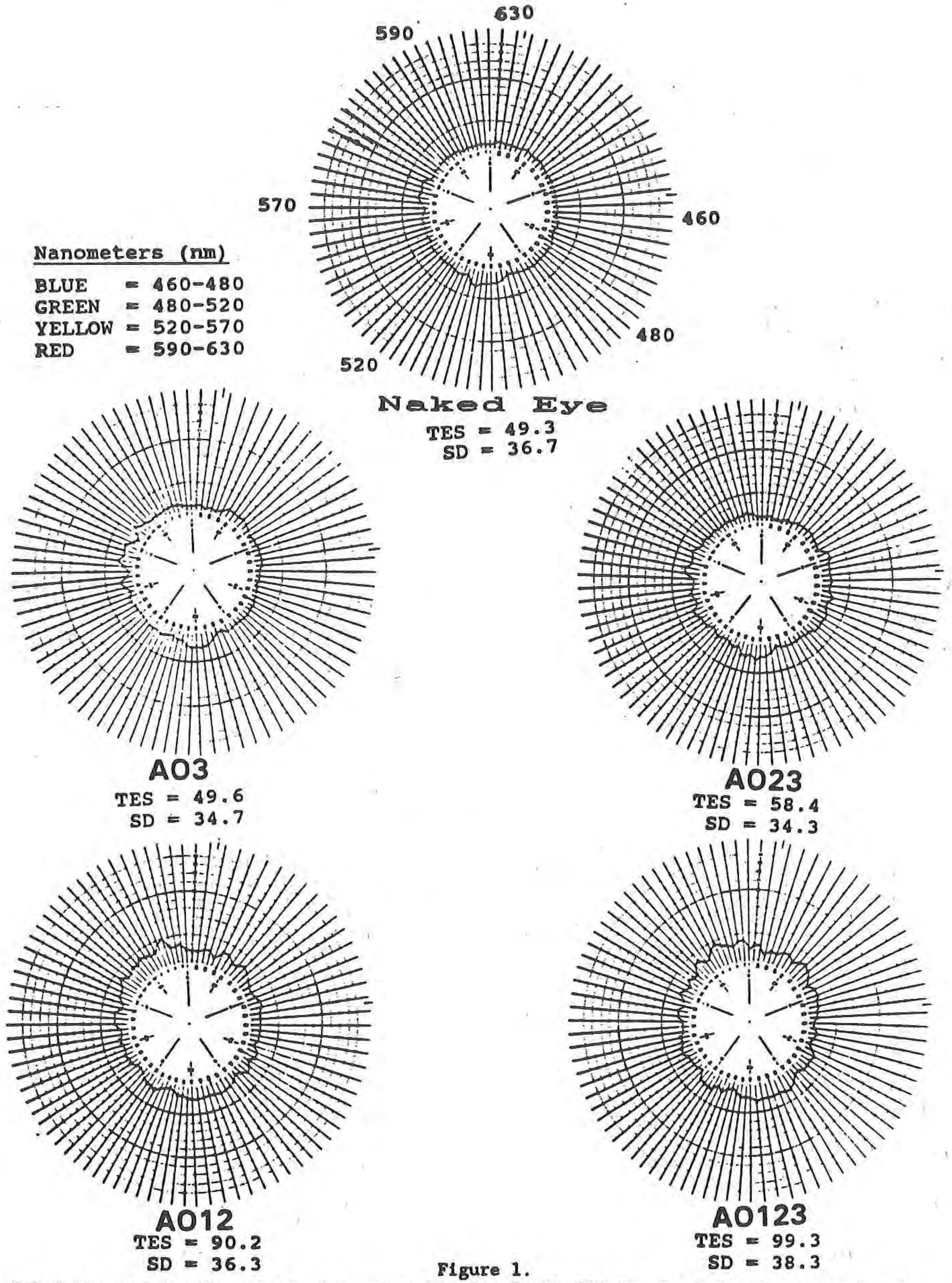

Figure 1.
Naked Eye and American Optical Lenses: Daytime F.-M. 100 Hue Test Results Scored and Plotted on a Chromaticity Circle. N=18; TES=Total Error Score Avg.; SD=Std. Deviation.

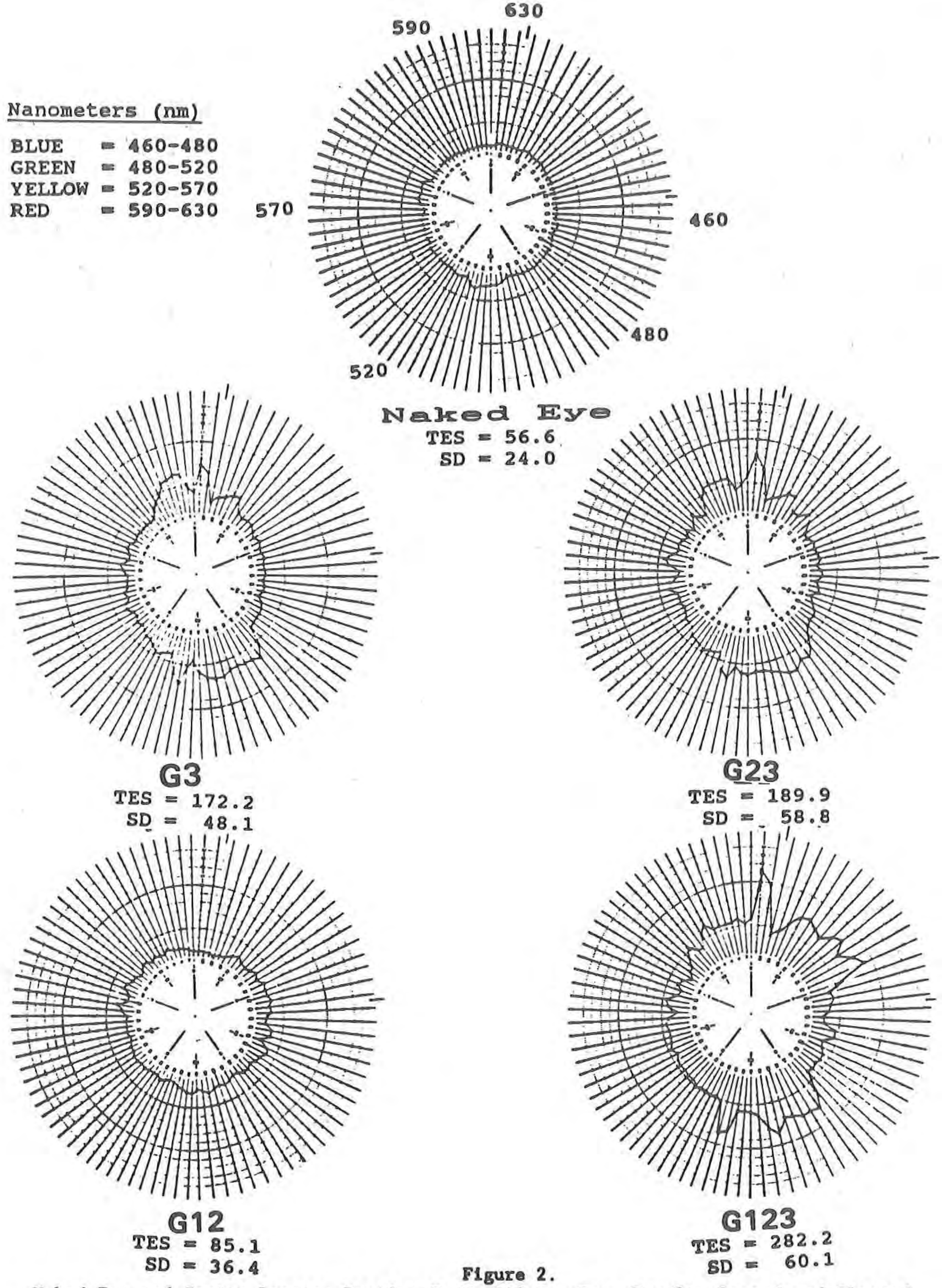

Figure 2.
Naked Eye and Gentex Lenses: Daytime F.-M. 100 Hue Test Results Scored and Plotted on a Chromaticity Circle. N=19; TES=Total Error Score Avg.; SD=Std. Deviation.

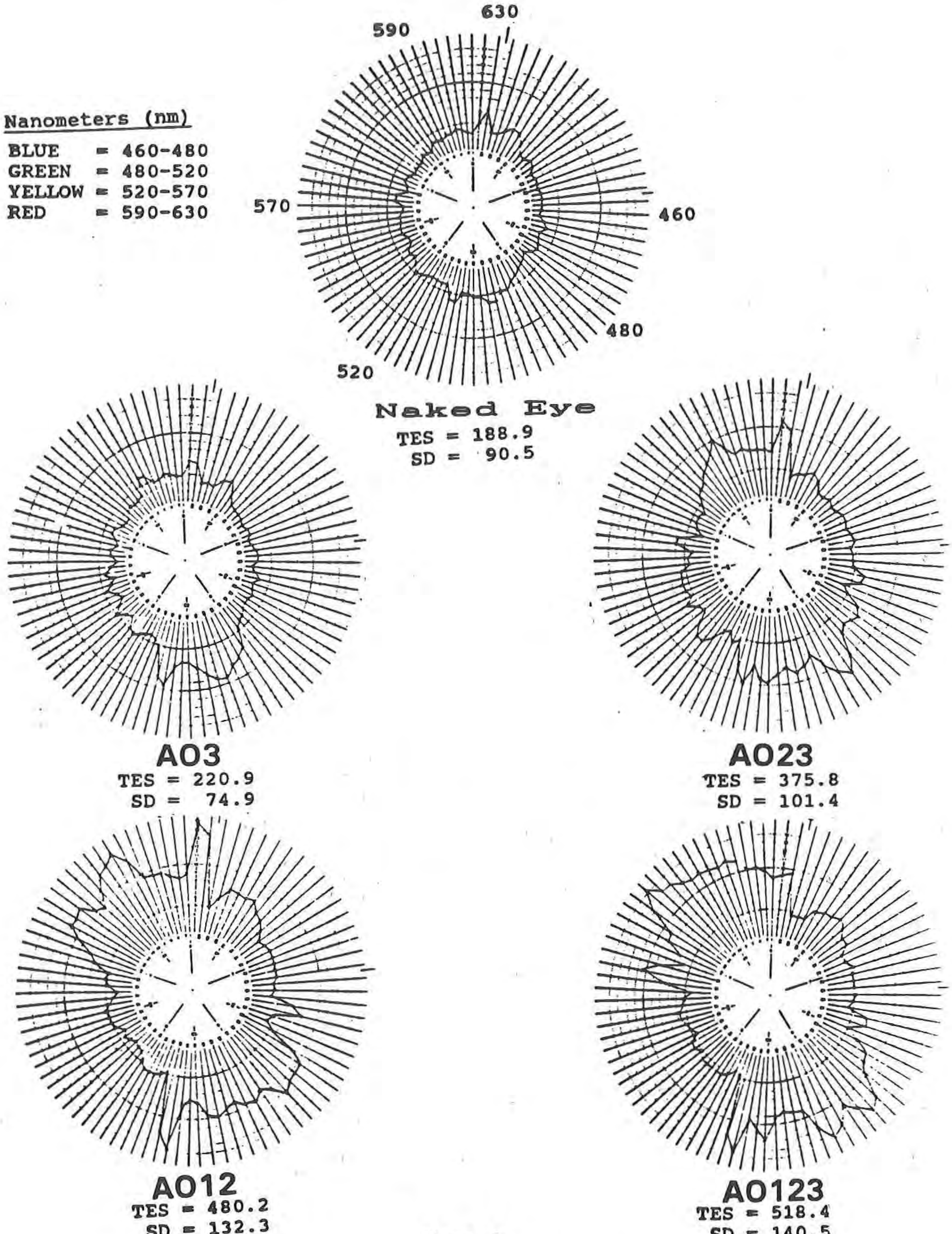

Figure 3.
Naked Eye and American Optical Lenses: Dusk F.-M. 100 Hue Test Results Scored and Plotted on a Chromaticity Circle. N=18; TES=Total Error Score Avg.; SD=Std. Deviation.

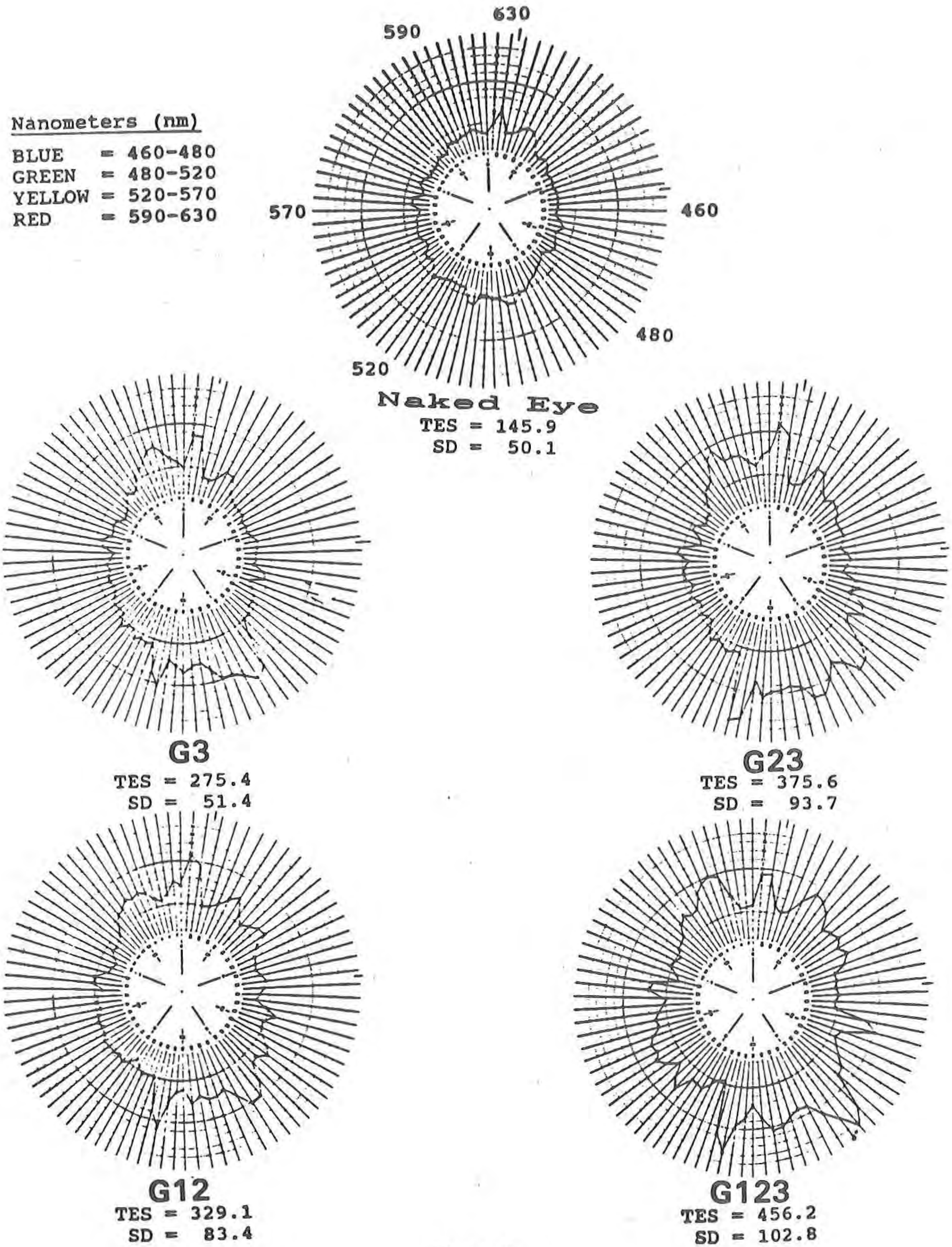

Figure 4.
Naked Eye and Gentex Lenses: Dusk F.-M. 100 Hue Test Results Scored and Plotted on a Chromaticity Circle. N=19; TES=Total Error Score Avg.; SD=Std. Deviation.

its respective circle. There is a naked eye (NE) result for each brand for each condition as well.

The naked eye profiles in the two daylight conditions show the same results that anyone with average discrimination would attain. (Sixty-eight percent of the population with normal color vision would attain a score between 20 and 100 on the first try at this test.)

Average TES's fall in a normal range for all of the AO lenses in the daylight condition, and the errors appear around the color circle, with no obvious polarization (clustering of errors in a particular color zone). The discrimination pattern is quite different for the Gentex lenses in daylight. Although the errors for the G12 lens fall around the color circle, the other three lenses show some distinct, but not extreme, polarization in the red-green spectra. The TESs for all lenses except G12 exceed 100.

The naked eye profiles in the dusk condition show a higher-than-normal error profile, with some indications of red-green polarization. This reflects the normal cone-to-rod shift in color perception that occurs at night. The AO3 lens profile in the dusk condition is more polarized than the naked eye profile, but the other three AO lenses show strong polarization.

The dusk AO23 polarizations are pronounced in the red/orange and blue/green wavelengths. Those same polarizations increase in the AO12 and infringe on the yellow wavelengths as well. The AO123 polarizations are pronounced in the green-blue, orange-red, and yellow areas.

The Gentex 3 and 23 lenses are fairly similar to their dusk counterparts in the AO, as is the G12, but the 12 Gentex is less polarized than its counterpart. The G123 shows fairly high error rates around the color circle, with a strong polarization in the blue-green to purplish-blue spectra. The TESs for the lenses of both brands are all worse than their naked eye conditions, and exacerbate with increasing levels of protection.

While not discussed in the test manual, square root transformations of error scores are commonly used to analyze test results, as this transformation yields a more normal distribution of error scores. We therefore derived the square root of the TES (SQR TES) for each condition for each lens, as well as an average square root error score for a blue-yellow partition of the error scores (SQR B-Y) and a red-green partition (SQR R-G). We then conducted MANOVAs on these scores for the 5 factors (TES, SQR TES, SQR B-Y, SQR R-G, and DIFF) for all lenses and the naked eye for each condition. A difference score of the square root partitions was also computed (DIFF) by subtracting the SQR R-G from the SQR B-Y. The DIFF indicates whether the errors accumulated along the R-G or B-Y discrimination axis. A positive number indicates a B-Y axis, a negative a R-G axis.

Thus, TES and SQR TES quantify the degree of color discrimination loss for the entire color range, SQR B-Y and SQR R-G quantify specific partitions of it, and DIFF indicates around which color axis the errors are clustered.

Table 3 displays the averages and standard deviations for day and dusk conditions for the TES, SQR TES, SQR B-Y, SQR R-G, and DIFF factors for each of the American Optical and Gentex lenses. The table also displays the MANOVA results conducted on each factor. Figures 5-8 show the graphs of the SQR TES, SQR B-Y, SQR R-G for each illumination level and brand shown in Table 2.

The MANOVAs conducted on the daylight data show that brand has an effect on performance, as does the type of lens (number of laser lines). This was true for all five factors in the daylight condition. Overall, AO outperformed Gentex in daytime.

While MANOVAs show if differences exist with regard to brand or type of lens, they do not show where the specific differences lie. Post hoc SNK tests used for that purpose showed the significant differences that existed at the .05 criterion level for the SQR TES means for day and dusk conditions and are indicated in Tables 4 and 5, respectively.

In the daylight condition, the AO lenses divided into two groups: AO123 and AO12 scores were significantly worse than the scores of the other two lenses and the naked eye condition. AO3 and AO23 scores were not statistically different from the naked eye score. No SQR TES for any lens exceeded error values for average discrimination ability, however.

The Gentex daylight condition differed from the American Optical. With one exception all Gentex lenses are statistically different from each other, as well as from the naked eye. The exception is the relationship of G3 and G23; there is no difference in those two. The rank order of the lenses in terms of increasing error scores is: naked eye; G12; G3; G23; G123.

In the daylight condition AO3, AO23, and AO123 were all significantly better than their respective Gentex counterparts.

MANOVAs showed that brand had no effect for any factor at dusk, but the type of lens did for all five factors. (This does not mean that there cannot be some brand differences between individual lenses).

The dusk condition for the AO showed that all lenses were significantly different from each other as well as the naked eye, with the exception of AO12 and AO123; those two did not differ from each other. They were the worst performers, with the naked eye being the best, and AO3 and AO23 ranking second and third respectively.

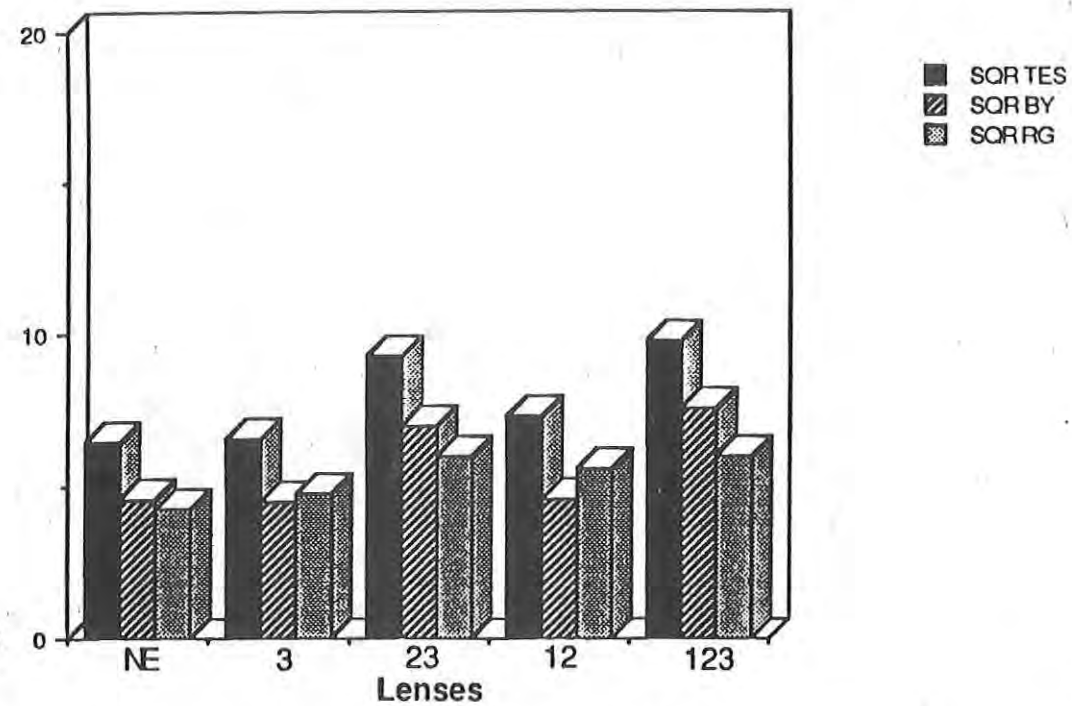

Figure 5

Square Root Total Error Scores
American Optical - Day Condition

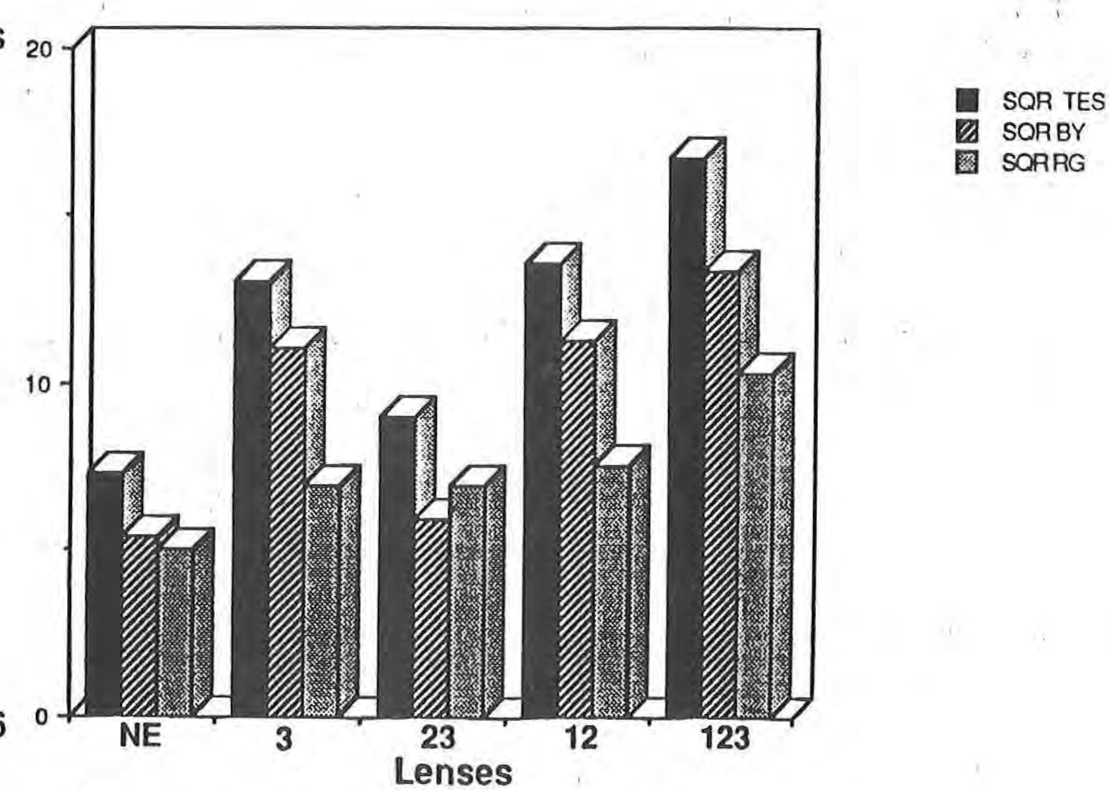

Figure 6

Square Root Total Error Scores
Gentex - Day Condition

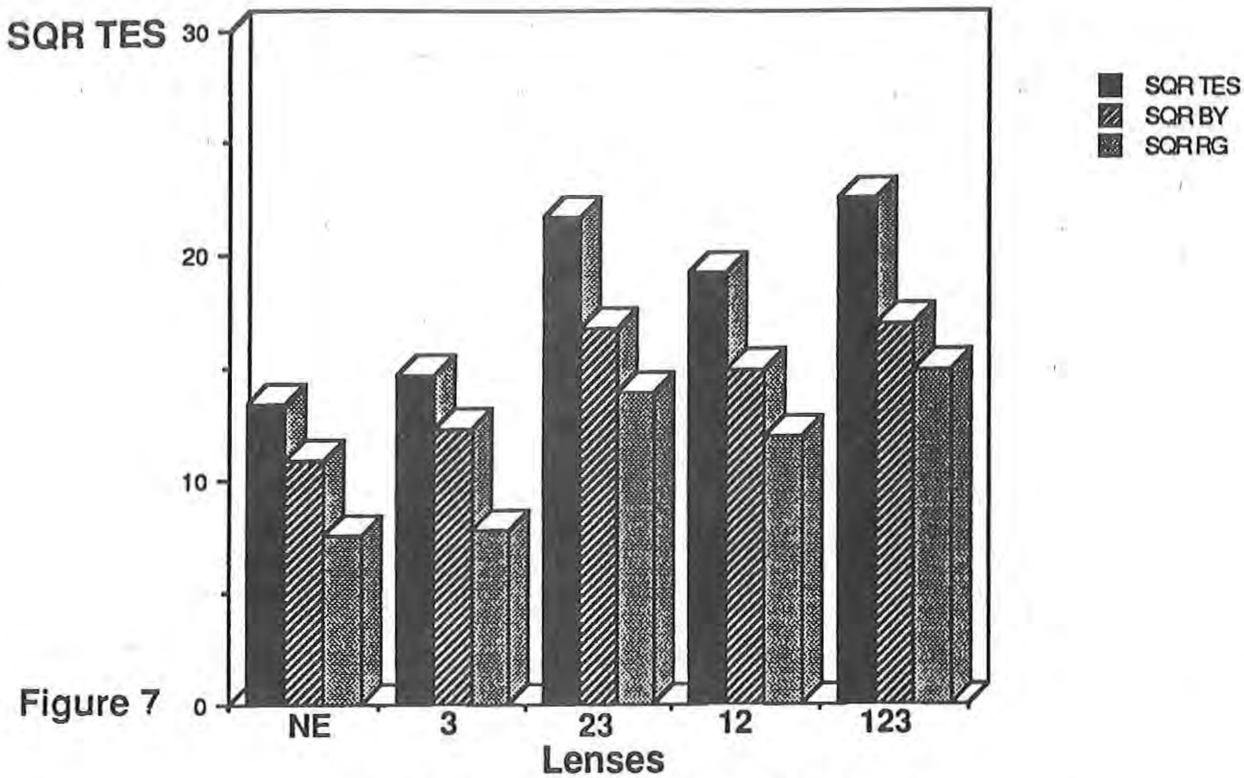

Figure 7

Square Root Total Error Scores
American Optical - Dusk Condition

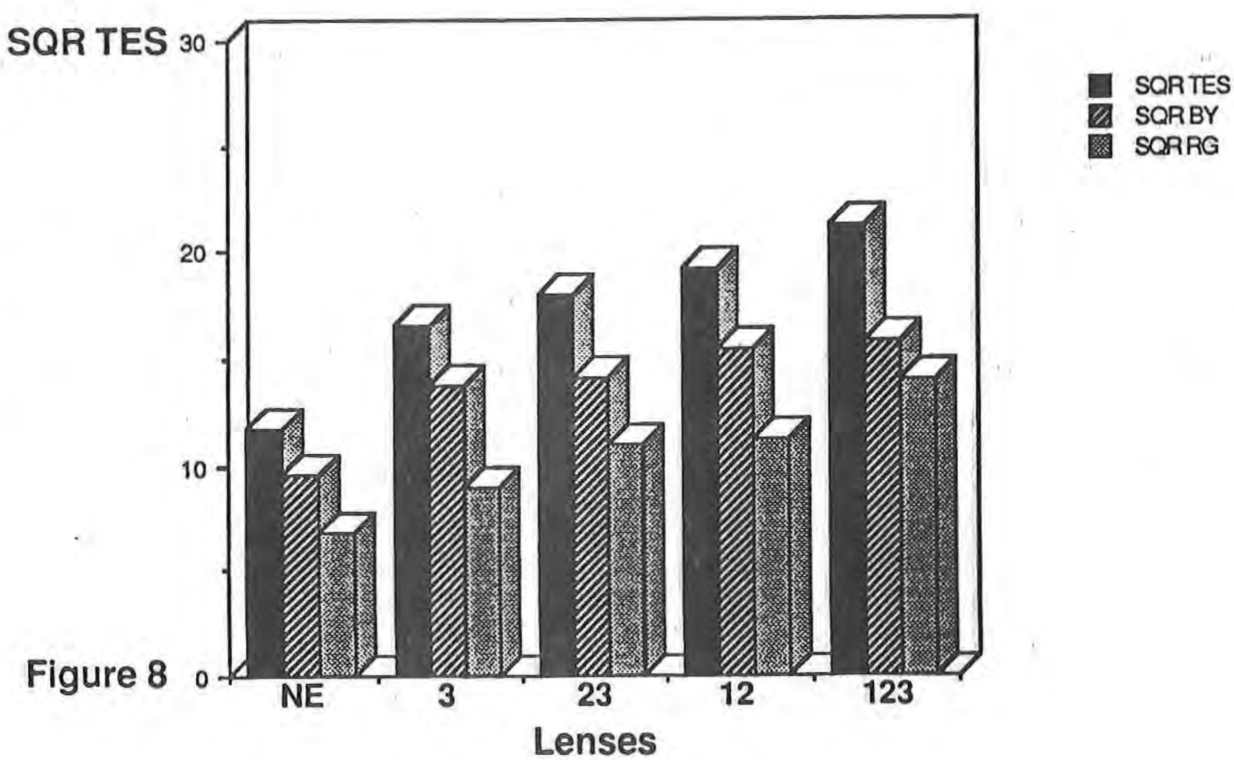

Figure 8

Square Root Total Error Scores
Gentex - Dusk Condition

TABLE 3

MANOVA'S BY GOGGLE BRAND FOR THE DAY CONDITION
FARNSWORTH - MUNSELL 100 HUE TEST

FACTOR	NE X	NE SD	I3 X	I3 SD	I1,2 X	I1,2 SD	I2,3 X	I2,3 SD	I1,2,3 X	I1,2,3 SD	BRAND	LENS	B*L
TES													
AO	49.3	36.7	49.6	34.7	90.2	36.3	58.4	34.3	99.3	38.3	p=.000	p=.000	p=.000
GENTEX	56.6	24.0	172.2	48.1	85.1	36.4	189.9	58.8	282.9	60.1			
SQR TES													
AO	6.5	2.7	6.6	2.5	9.3	2.0	7.3	2.4	9.8	1.9	p=.000	p=.000	p=.000
GENTEX	7.3	1.7	13.0	1.8	9.0	1.9	13.6	2.1	16.7	1.8			
SQR B-Y													
AO	4.6	2.4	4.5	2.1	7.0	1.7	4.6	1.6	7.6	1.8	p=.000	p=.000	p=.000
GENTEX	5.4	1.3	11.0	1.5	5.9	1.4	11.3	2.0	13.3	2.0			
SQR R-G													
AO	4.3	1.9	4.8	1.7	6.0	1.4	5.6	1.9	6.0	1.3	p=.000	p=.000	p=.000
GENTEX	5.0	1.3	6.9	1.3	6.9	1.7	7.5	1.3	10.3	1.1			
DIFFERENCE SQR R-G, B-Y													
AO	.3	1.7	-.3	1.0	1.0	1.4	-.9	1.2	1.6	1.7	p=.000	p=.000	p=.000
GENTEX	.4	1.0	4.2	1.4	-.8	1.4	3.9	1.7	3.2	2.0			

MANOVA'S BY GOGGLE BRAND FOR THE DUSK CONDITION
FARNSWORTH - MUNSELL 100 HUE TEST

FACTOR	NE X	NE SD	I3 X	I3 SD	I1,2 X	I1,2 SD	I2,3 X	I2,3 SD	I1,2,3 X	I1,2,3 SD	BRAND	LENS	B*L
TES													
AO	188.9	90.5	220.9	74.9	480.2	132.3	375.5	101.4	518.4	140.5	NS	p=.000	p=.000
GENTEX	145.9	50.1	275.4	51.4	329.1	83.4	375.6	93.7	456.2	102.8			
SQR TES													
AO	13.4	3.2	14.7	2.6	21.7	3.0	19.2	2.7	22.6	3.1	NS	p=.000	p=.000
GENTEX	11.8	2.6	16.5	1.5	18.0	2.4	19.2	2.3	21.2	2.5			
SQR B-Y													
AO	10.9	2.1	12.3	1.9	16.7	2.0	14.9	1.8	16.7	1.9	NS	p=.000	p=.000
GENTEX	9.6	2.3	13.8	1.0	14.2	1.9	15.5	1.2	15.9	1.3			
SQR R-G													
AO	7.6	2.9	7.8	2.3	13.9	2.6	12.0	2.4	14.9	2.9	NS	p=.000	p=.000
GENTEX	6.8	1.7	9.0	1.8	11.0	1.9	11.3	2.7	14.0	2.7			
DIFFERENCE SQR R-G, B-Y													
AO	3.3	1.7	4.5	1.8	2.8	2.0	2.9	1.8	2.0	2.0	NS	p=.000	NS
GENTEX	2.9	1.8	4.8	1.8	3.1	1.5	4.2	2.3	1.9	2.1			

TABLE 4
Significant Differences
Total Error Scores (SQR TES)
DAY CONDITION

Mean	Lens	6.5 AO NE	6.6 AO 3	9.3 AO 2,3	7.3 AO 1,2	9.8 AO 1,2,3
6.5	AO NE					
6.6	AO 3					
9.3	AO 2,3					
7.3	AO 1,2	*	*	*		
9.8	AO 1,2,3	*	*	*		

Mean	Lens	6.5 GEN NE	6.6 GEN 1,2	9.3 GEN,3	7.3 GEN 2,3	9.8 GEN 1,2,3
6.5	GEN NE					
6.6	GEN 3	*				
9.3	GEN 2,3	*	*			
7.3	GEN 1,2	*		*		
9.8	GEN 1,2,3	*	*	*	*	

SIGNIFICANT DIFFERENCES BETWEEN BRANDS

1. Gentex 3 (X = 13.0) and American Optical 3 (X = 6.6)
2. Gentex 2,3 (X = 13.6) and American Optical 2,3 (X = 7.3)
3. Gentex 1,2,3 (X = 16.7) and American Optical 1,2,3 (X = 9.8)

TABLE 5
Significant Difference Results for the
Total Error Scores (SQR TES)
DUSK CONDITION

Mean	Lens	13.4 AO NE	14.7 AO 3	19.2 AO 2,3	21.7 AO 1,2	22.6 AO 1,2,3
13.4	AO NE					
14.7	AO 3	*				
19.2	AO 2,3	*	*			
21.7	AO 1,2	*	*	*		
22.6	AO 1,2,3	*	*	*		

Mean	Lens	11.8 GEN NE	16.5 GEN 3	18.0 GEN 2,3	19.2 GEN 1,2	21.2 GEN 1,2,3
11.8	GEN NE					
16.5	GEN 3	*				
18.0	GEN 2,3	*	*			
19.2	GEN 1,2	*	*	*		
21.2	GEN 1,2,3	*	*	*	*	

SIGNIFICANT DIFFERENCES BETWEEN BRANDS

1. Gentex NE (X = 11.8) and American Optical NE (X = 13.4)
2. Gentex 3 (X = 16.5) and American Optical 3 (X = 14.7)
3. Gentex 1,2 (X = 18.0) and American Optical 1,2 (X = 21.7)
4. Gentex 1,2,3 (X = 21.2) and American Optical 1,2,3 (X = 22.6)

The dusk condition for the Gentex showed that all lenses were significantly different from each other and from the naked eye, with the progression from best to worst being: naked eye; G3; G23; G12; G123. At dusk, the counterparts in the brands that were significantly different were the 3, 12, and 123 levels, with the Gentex being the better performer in the 12 and 123 levels.

While there were no significant differences in means for the naked eye condition in daylight, there were for dusk in both the TES and SQR TES. The implication is ther may be some difference in two brand groups for the dusk condition. We feel that the difference is too small to be of much concern. Scientific literature on this test - as well as the wide variance we see in our test results - seems to indicate that a difference in any two square root scores of less than 2 would not mean much in a practical sense. This distinction of practical versus statistical difference should also be kept in mind when reading the test result tables under discussion.[6]

Tables 6-9 show the post-hoc results for the partitioned blue-yellow (SQR B-Y) and green-red (SQR G-R) errors for daylight and dusk. The daylight differences for both partitioned scores generally mirror the unpartitioned daylight scores shown in Table 4. There are fewer differences among lenses in the SQR G-R for both lens brands. Also, AO12 differs significantly from G12 in both daylight color partitions; AO12 is slightly better in the SQR G-R and worse in the SQR B-Y.

There is nothing striking about the significant differences in the error scores for the dusk condition. They are generally consistent with total error scores.

The interactions of brand and lens were significant for all factors for both light conditions except for the DIFF score in the dusk condition. Significance here simply means that the brand did not have a relatively uniform effect on test performance with respect to the different levels of laser protection.

DIFF scores were calculated merely to show differences in polarity within a given level of laser protection. No post-hoc comparisons were conducted, as those comparisons are more meaningfully covered in the SQR TES color partition discussions.

Conclusions

The AO lenses all performed in normal error ranges for daytime, while all Gentex lenses exceeded them except for Gentex 12.

Dusk condition error rates for all lenses exceeded normal error ranges, but so did the naked eye values. At dusk however, there were still substantial differences among the lenses, with the lenses having 3 lines of protection being the poorest performers and the ones with a single line being the best.

TABLE 6
Significant Differences
Blue - Yellow Error Scores (SQR BY)
DAY CONDITION

Mean	Lens	4.5 AO 3	7.0 AO 2,3	4.6 AO NE	4.6 AO 1,2	7.6 AO 1,2,3
4.5	AO 3					
7.0	AO 2,3					
4.6	AO NE					
4.6	AO 1,2	*	*	*		
7.6	AO 1,2,3	*	*	*		

Mean	Lens	5.4 GEN NE	5.9 GEN 1,2	11.0 GEN 3	11.3 GEN 2,3	13.3 GEN 1,2,3
5.4	GEN NE					
5.9	GEN 1,2					
11.0	GEN 3	*	*			
11.3	GEN 2,3	*	*			
13.3	GEN 1,2,3	*	*	*	*	

SIGNIFICANT DIFFERENCES BETWEEN BRANDS

1. Gentex 3 (X = 11.0) and American Optical 3 (X = 4.5)
2. Gentex 2,3 (X = 11.3) and American Optical 2,3 (X = 7.0)
3. Gentex 1,2 (X = 5.9) and American Optical 1,2 (X = 4.6)
4. Gentex 1,2,3 (X = 13.3) and American Optical 1,2,3 (X = 7.6)

TABLE 7
Significant Differences
Blue - Yellow Error Scores (SQR BY)
DUSK CONDITION

Mean	Lens	10.9 AO NE	12.2 AO 3	14.9 AO 2,3	16.7 AO 1,2	16.9 AO 1,2,3
10.9	AO NE					
12.2	AO 3	*				
14.9	AO 2,3	*	*			
16.7	AO 1,2	*	*	*		
16.9	AO 1,2,3	*	*	*		

Mean	Lens	9.6 GEN NE	13.8 GEN 3	14.2 GEN 1,2	15.5 GEN 2,3	15.9 GEN 1,2,3
9.6	GEN NE					
13.8	GEN 3	*				
14.2	GEN 1,2	*				
15.5	GEN 2,3	*	*	*		
15.9	GEN 1,2,3	*	*	*		

SIGNIFICANT DIFFERENCES BETWEEN BRANDS

1. Gentex NE (X = 9.6) and American Optical NE (X = 10.9)
2. Gentex 3 (X = 13.8) and American Optical 3 (X = 12.2)
3. Gentex 1,2 (X = 14.2) and American Optical 1,2 (X = 16.7)

TABLE 8
Significant Differences
Red - Green Error Scores (SQR RG)
DAY CONDITION

Mean	Lens	4.3 AO NE	4.8 AO 3	5.6 AO 2,3	6.0 AO 1,2,3	6.0 AO 1,2
4.3	AO NE					
4.8	AO 3					
5.6	AO 2,3	*				
6.0	AO 1,2,3	*	*			
6.0	AO 1,2	*	*			

Mean	Lens	5.0 GEN NE	6.9 GEN 1,2	6.9 GEN 3	7.5 GEN 2,3	10.3 GEN 1,2,3
5.0	GEN NE					
6.9	GEN 1,2	*				
6.9	GEN 3	*				
7.5	GEN 2,3	*				
10.3	GEN 1,2,3	*	*	*	*	

SIGNIFICANT DIFFERENCES BETWEEN BRANDS

1. Gentex 3 (X = 6.9) and American Optical 3 (X = 4.8)
2. Gentex 2,3 (X = 7.5) and American Optical 2,3 (X = 5.6)
3. Gentex 1,2,3 (X = 10.3) and American Optical 1,2,3 (X = 6.0)
4. Gentex 1,2 (X = 6.9) and American Optical 1,2 (X = 6.0)

TABLE 9
Significant Differences
Red - Green Error Scores (SQR RG)
DUSK CONDITION

Mean	Lens	7.6 AO NE	7.8 AO 3	12.0 AO 2,3	13.9 AO 1,2	14.9 AO 1,2,3
7.6	AO NE					
7.8	AO 3					
12.0	AO 2,3	*	*			
13.9	AO 1,2	*	*	*		
14.9	AO 1,2,3	*	*	*		

Mean	Lens	6.8 GEN NE	9.0 GEN 3	11.0 GEN 1,2	11.3 GEN 2,3	14.0 GEN 1,2,3
6.8	GEN NE					
9.0	GEN 3	*				
11.0	GEN 1,2	*	*			
11.3	GEN 2,3	*	*			
14.0	GEN 1,2,3	*	*	*	*	

SIGNIFICANT DIFFERENCES BETWEEN BRANDS

1. Gentex 3 (X = 9.0) and American Optical 3 (X = 7.8)
2. Gentex 1,2 (X = 11.0) and American Optical 1,2 (X = 13.9)

Although statistically different, the AO3 did not differ from the naked eye in practical terms. There was also polarization primarily in the red-green portion of the spectrum at dusk for all lenses, that grew more pronounced with increasing levels of protection.

In general, color discrimination becomes worse with increasing lines of protection, and dusk exacerbates the conditions further. The red and green portions of the spectrum are affected more than any other.

It must be noted that the lenses differ in a number of ways. They can have different optical densities for the same line(s) of protection. They have varying transmittance levels for night and day which are not necessarily correlated with the number of lines of protection, and they are not all the same tint. So, while we can compare error scores from one lens to another, we cannot assess the influence a variable like tint would have accuracy the level of performance in the field considering the infinite range of illumination levels and colors that exist in a field environment, but they can serve as a frame of reference.

TARGET DETECTION TEST

Objective

To determine if the lenses affect target detection abilities.

Test Procedure/Participants

Soldiers rated how easy or difficult it was to detect targets on an automated M-16 qualification range at distances of 50, 100, 150, 200, 250, and 300 meters. Five target arrays were selected for use that were based on the standard qualification arrays, in which each array consists of 5 pop-up targets at different distances. The targets were mock-ups of white-faced human figures about 3' tall wearing green helmets and having green bodies with a red stripe across the abdomen representing a weapon. Four subjects were tested at a time, each on a different firing lane. Subject assignment to lanes was random, but the same four lanes of the 16-lane range were always used. Each subject stood in a foxhole in his respective lane facing downrange and went through the five arrays.

The presentation order and distance compositions of the arrays were the same for all subjects. The first array was always a naked eye condition, and the subsequent four were used to test randomized sequences of lenses - one type of lens per array. The lenses were: AO3; AO23; AO12; and AO123(B) or AO123(P). A few samples of the AO123(P) were brought to the test site after testing had begun and randomly alternated with the AO123(B).

The lanes had different levels of ground cover, but generally speaking, two had fairly light ground cover and two were heavily forested. The test was conducted for two days during the week of August 24th at Ft. Polk. The dusk condition part of the test was started at 1930 hours. We refer to the reduced visibility condition as dusk, but technically, though the sun was setting, it was not always dusk by definition (dusk: the deepest part of twilight). Some of the light readings for the day and dusk conditions overlapped, but overall there was a difference in the two light conditions.

Light readings were taken at all lanes on the range with a LiteMate/SpotMate System 500 Photometer. Readings were taken every hour during daylight and every 30 minutes at dusk. The daylight readings ranged from 212 to 20,000 foot-candles; the average was 5484 (SD=6446) and the median reading was 2060 foot-candles. The dusk readings ranged from .35 to 4940 foot-candles, with the average being 980 (SD=1659) and the median 117. There was considerable variability even in the readings taken at the same time on the different lanes because of the differences in ground cover/location.

A total of 48 enlisted soldiers from the 1st Brigade, 5th Armor Division were tested - 27 in the daylight condition and 21 in the dusk. There were no meaningful demographic differences between the subgroups. The average age was 23, and the ranks ranged from E-1 to E-6, with the majority (85%) being E-3s and E-4s. All but five were combat vehicle crewmen. Some of the subjects were sent by the units to both test conditions; it is not clear how many.

Results

Soldiers rated how easy or difficult it was to detect the targets on the following scale:

Very Difficult	Slightly Difficult	Neither Difficult Nor Easy	Slightly Easy	Very Easy
1	2	3	4	5

Table 10 shows the mean ratings. The daylight ratings stay on the easy side of the scale for distances up to and including 200m for all lenses except the AO123(P) lens; its ratings were neutral at 150 and 200m, but the sample size is so small the ratings cannot be considered conclusive. At 250m the average daylight ratings for the lenses fall in the neutral category, while detecting the target with the naked eye is considered "slightly easy." At 300m daylight ratings range from slightly difficult to neutral; the rating for the naked eye is no more than a half scale point different from any lens except the AO123(P), which again has a very small sample size contributing to the rating.

TABLE 10

TARGET DETECTION MEAN RATINGS

(1 = VERY DIFFICULT; 5 = VERY EASY)

DAY:

	50m			100m			150m			200m			250m			300m		
	X	SD	N	X	SD	N	X	SD	N	X	SD	N	X	SD	N	X	SD	N
A03	5.0	.0	21	4.7	.7	27	4.4	.8	27	3.8	1.4	27	3.1	1.2	7	3.1	1.6	20
A02,3	5.0	.0	20	4.6	.6	27	4.4	.8	27	3.9	1.2	27	3.4	1.2	27	2.6	1.6	20
A01,2	5.0	.0	20	4.6	.8	27	4.2	.9	27	3.9	1.2	27	2.7	1.4	6	2.5	1.6	21
A01,2,3(B)	4.9	.3	13	4.9	.4	20	4.4	1.1	20	4.2	1.1	20	3.6	1.6	7	2.6	1.4	13
A01,2,3(P)	5.0	.0	7	4.1	.9	7	3.3	1.4	7	2.7	1.1	7	-	-	-	1.7	1.3	7
NAKED EYE	5.0	.0	27	4.9	.3	27	-	-	-	-	-	-	3.9	1.0	27	3.0	1.6	27

DUSK:

	50m			100m			150m			200m			250m			300m		
	X	SD	N	X	SD	N	X	SD	N	X	SD	N	X	SD	N	X	SD	N
A03	4.9	.3	15	4.2	1.1	21	3.8	1.4	21	3.0	1.4	21	2.4	1.5	5	2.1	1.3	16
A02,3	4.6	1.1	16	4.0	1.5	21	3.7	1.3	21	3.0	1.5	21	2.8	1.8	5	1.8	1.1	16
A01,2	4.6	.9	16	3.3	1.4	21	2.9	1.5	21	2.6	1.4	21	1.8	1.2	6	1.7	1.2	15
A01,2,3(B)	4.5	1.2	11	3.4	1.6	16	2.8	1.6	16	2.4	1.9	16	1.0	.0	5	1.5	.9	11
A01,2,3(P)	4.6	.9	5	2.6	1.8	5	2.4	1.5	5	1.6	.9	5	-	-	-	1.2	.4	5
NAKED EYE	4.9	.7	21	4.8	.4	21	-	-	-	-	-	-	3.1	1.4	21	2.3	1.6	21

The dusk ratings also show worsening ratings with increasing distance, and poorer ratings overall compared to daylight ratings, as expected. Here the average ratings for all the lenses are neutral or worse by 200m; all the ratings at 300m, to include the naked eye rating, are on the slightly to very difficult side of the scale.

We conducted one-way ANOVAs on the day and dusk conditions to determine if there were any statistically significant effects due to lens or distance. Complete lack of data in some of the cells and a paucity in others caused us to drop the AO123(P) lens from the ANOVAs along with the 150m and 200m distances. The data in the remaining cells were then weighted to offset any bias created by unequal cell sizes.

The ANOVA conducted on the daytime data did not quite show significance for type of lens, but there was a clear effect for distance, as shown in Table 11. That is, the type of lens made little difference in how well the soldiers reported being able to detect the target for any given distance, but increasing distance did have its expected ill effect.

There was no significant interaction of lens and distance. The relationships of distances and ability to see showed a progressive downward trend, with no significant change in the direction of the mean at any distance. Figure 9 shows the graph of the daytime mean ratings for the different lenses at the distances in question.

TABLE 11
ANALYSIS OF VARIANCE OF TARGET DETECTION RATINGS
FOR FOUR AO LENSES* AND THE NAKED EYE IN DAYLIGHT

SOURCE OF VARIATION	SUM OF SQUARES	df	MEAN SQUARE	F	SIGNIFICANCE OF F
LENS	9.89	4	2.47	2.18	.071
DISTANCE	337.99	3	112.66	99.18	.000
LENS/DISTANCE INTERACTION	12.47	12	1.03	.91	.532
TOTAL	773.85	383	2.02		

* AO3; AO12; AO23; AO123(B)

Post-hoc SNK findings for the daylight distance means are in Table 12:

TABLE 12 (N=96)

RESULTS OF THE STUDENT-NEWMAN-KEULS PROCEDURE
FOR THE EFFECT OF DISTANCE IN DAYLIGHT (5=VERY EASY)

Distance	50m	100m	250m	300m
Mean rating	<u>4.98</u>	<u>4.74</u>	3.33	2.75

All the means are significantly different from each other except the two underlined distances - 50m and 100m. That is, the means for 250m and 300m each differ from the other three means as well as from each other.

The ANOVA conducted on the ratings collected at dusk showed significant effects for both lens and distance, but again there was no significant effect for interaction. In this condition the type of lens did make a difference in ability to detect a target as did distance. The ANOVA findings for the dusk condition are in Table 13. The graph of the mean dusk ratings for each lens at each distance is shown in Figure 10.

TABLE 13
ANALYSIS OF VARIANCE OF TARGET DETECTION RATINGS
FOR FOUR AO LENSES* AND THE NAKED EYE AT DUSK

SOURCE OF VARIATION	SUM OF SQUARES	df	MEAN SQUARE	F	SIGNIFICANCE OF F
LENS	49.93	4	12.48	9.01	.000
DISTANCE	409.29	3	136.43	98.34	.000
LENS/DISTANCE INTERACTION	20.82	12	1.74	1.25	.247
TOTAL	868.12	299	2.90		

*AO3; AO12; AO23; AO123(B)

Post-hoc SNK findings for the dusk lens and distance means are in Table 14. All the means for each variable are significantly different from each other except those that are underlined. While it is significantly more difficult to detect a target at 100m than 50m, the difficulty levels are similar for 250m and 300m, although it is much more difficult to see the targets at those distances overall. For the lenses, the mean for the naked eye is not significantly different from those of AO23 and AO3, but seeing with those two lenses and the naked eye is significantly easier than with the AO12 and AO123(B). The AO12 and AO123(B) do not differ significantly from each other, however.

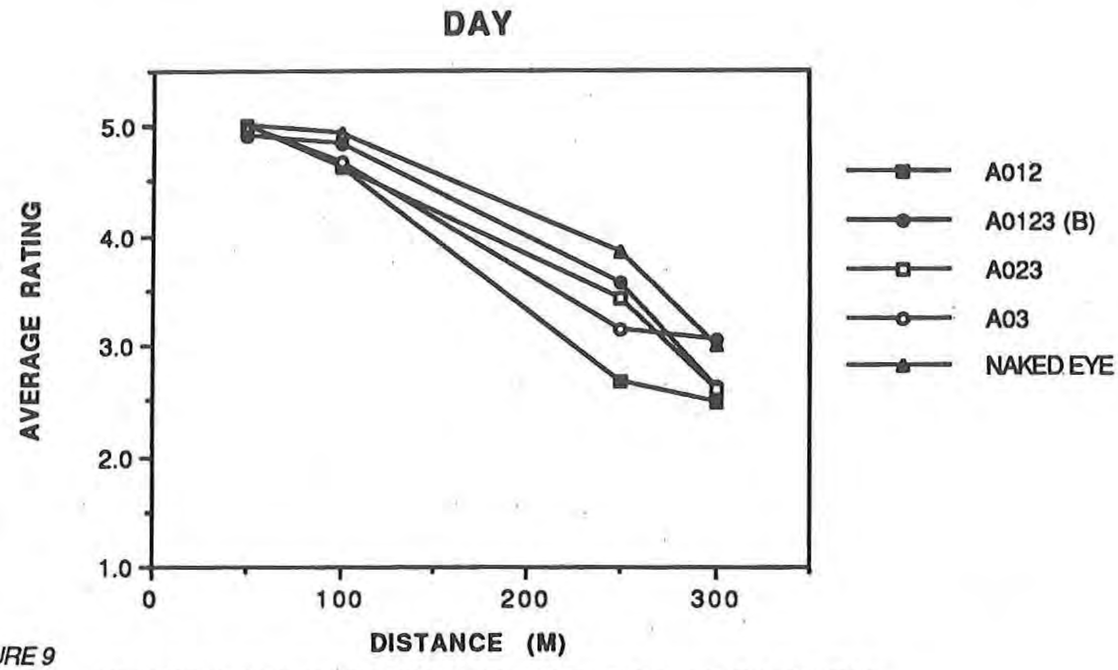

FIGURE 9

MEAN RATINGS OF ABILITY TO SEE TARGET IN DAYLIGHT CONDITION

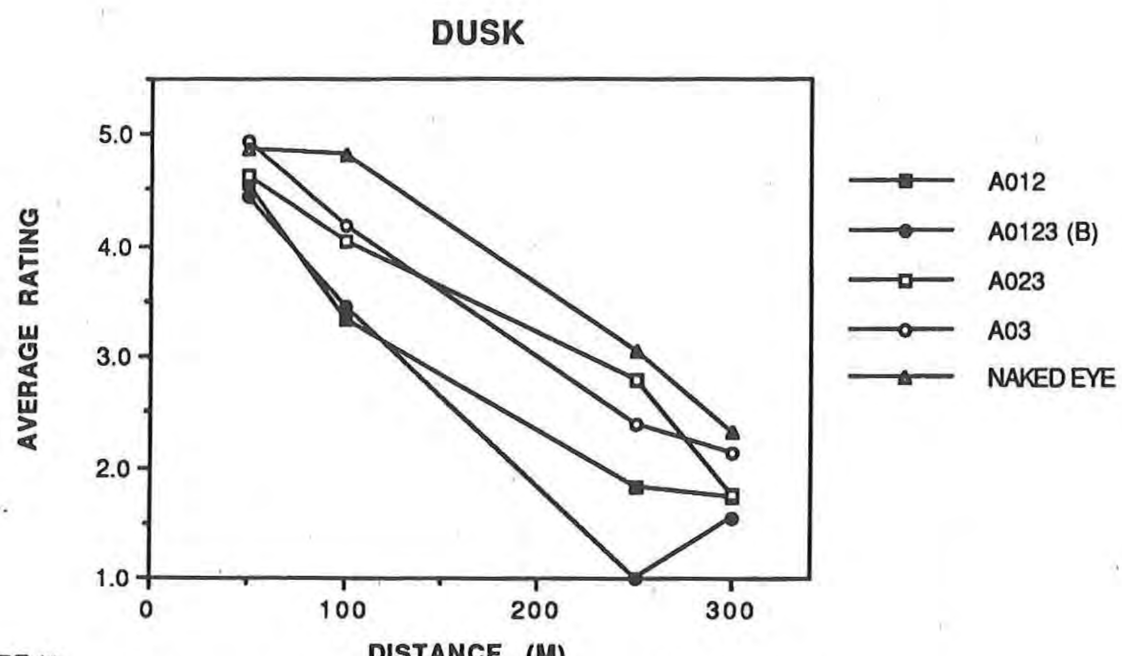

FIGURE 10

MEAN RATINGS OF ABILITY TO SEE TARGET IN DUSK CONDITION

TABLE 14

RESULTS OF THE STUDENT-NEWMAN-KEULS PROCEDURE
FOR THE EFFECTS OF DISTANCE AND LENS AT DUSK (5=VERY EASY)

Distance (N=75)	50m	100m	250m	300m
Mean rating	4.69	3.96	2.22	1.90

Lens (N=60)	AO123(B)	AO12	AO23	AO3	NAKED EYE
Mean rating	2.61	2.87	3.31	3.41	3.76

Conclusions

The data suggest the type of lens has no impact on the ability to detect a target in a bright daylight condition. With some reduced visibility (sundown), it appears that AO3 and AO23 are on par with the naked eye for target detection, while the AO123(B) and AO12 show some reported impairment of ease of detection, but the reported impairment is less than a scale point for either lens.

OPERATIONAL TESTING

Lens operational testing data were obtained from two sources: the 1st Brigade, 5th Infantry Division, at Ft. Polk, LA; and a reserve unit, Delta Troop, 5th Armored Cavalry, at Ft. Devens, MA. The Ft. Polk soldiers wore the goggles the short time it took to traverse a 3.5 kilometer tank trail and the Ft. Devens unit used the goggles for a weekend field training exercise.

The data sources were questionnaires, which differed according to site. The conditions were very different at the two sites in terms of climate, unit activity/mission while wearing the lenses, and types of lenses available for test. Moreover, due to time constraints, the Ft. Polk soldiers had to be administered a very short questionnaire.

Ft. Polk

The operational data were obtained from 84 armor crewmen of M1 Abrams tanks, most of whom were tank commanders and drivers, with an equal split between those two groups. The majority were enlisted, between the ranks E-3 and E-6, between the ages 20-28, and the median time in service was four years. These personnel wore either a AO123(B), AO123(P) or AO23 while they traversed a 3.5 km tank trail; median wear time for the lenses was 30

minutes. Their questionnaire data were obtained after they finished the tank trail. The climate was typical of Ft. Polk for August, i.e., hot and humid - in the 80 to 90^0+ range (Fahrenheit). The weather was sunny except for one rainy day during the four test days. The test was conducted only during daylight hours.

Ft. Devens

The 27 participants were operators and crewmembers of the M60A3 and the M113A3. The majority were enlisted, between the ranks E-2 and E-5 and ages 20-27, with an average of two years active duty. Almost all held armor Military Occupational Specialties (MOS's). Twenty-two soldiers were given either an AO23 lens and 5 an AO123(B) lens to wear on a local weekend training exercise in April, after which all filled out a questionnaire. The weather during that time was rainy and heavily overcast; the Fahrenheit temperatures were generally in the 50 degree range.

The median time values reported for wear of the AO23 lens were four hours for the daytime, 3/4 hour at night, and 1/2 hour at dusk. For the AO123 lens the values were two hours for day and 1/2 hour at dusk. Only two soldiers reported wearing them at night and their time averaged 20 minutes.

Table 15 shows the scale used and Ft. Polk average ratings for the overall ability to see.

TABLE 15
RATINGS FOR OVERALL ABILITY TO SEE (FT. POLK)

VERY BAD	MODERATELY BAD	SLIGHTLY BAD	NEITHER BAD NOR GOOD	SLIGHTLY GOOD	MODERATELY GOOD	VERY GOOD
1	2	3	4	5	6	7

LENS	X	SD	N
AO123(B)	6.1	1.1	38
AO123(P)	5.6	1.3	8
AO23	6.1	1.2	38

The ratings for the AO123(B) and AO23 are the same and highly acceptable. The AO123(P) also shows an acceptable rating, but the sample size is too small to rely on the rating.

Table 16 shows the average ratings for the suitability of the lenses for the field and for tactical situations at Ft. Polk.

TABLE 16
RATINGS OF LENS SUITABILITY FOR TACTICAL AND FIELD USE (FT. POLK)

VERY BAD	MODERATELY BAD	SLIGHTLY BAD	NEITHER BAD NOR GOOD	SLIGHTLY GOOD	MODERATELY GOOD	VERY GOOD
1	2	3	4	5	6	7

	TACTICAL SITUATION			FIELD USE OVERALL		
	N	X	SD	N	X	SD
AO Lens 123(B)	38	5.5	1.9	38	5.8	1.6
AO Lens 123(P)	6	5.3	1.6	6	5.0	1.7
AO Lens 23	35	5.5	1.6	35	5.9	1.3

The ratings for AO123(B) and AO23 are again the same and very acceptable for both lenses. The sample size is too small for the AO123(P) to be reliable.

The Ft. Devens soldiers rated their ability to see while wearing the lenses in a number of operational conditions. The scale used and the results are in Table 17.

TABLE 17
VEHICLE CONDITION AND AO23 AND AO123(B) LENSES (FT. DEVENS)

VERY BAD 1	MODERATELY BAD 2	SLIGHTLY BAD 3	NEITHER BAD NOR GOOD 4	SLIGHTLY GOOD 5	MODERATELY GOOD 6	VERY GOOD 7

	AO23 Lens			AO123(B) Lens		
Outside the vehicle:	X	SD	N	X	SD	N
Daylight	6.6	.8	20	4.8	2.2	5
Night						
Total darkness	2.9	2.0	16	-	-	
Blackout	2.8	1.9	11	-	-	
Dusk	4.7	1.8	16	4.4	1.7	5
Dawn	5.5	1.5	17	4.4	1.7	5
Inside "buttoned up" vehicle:						
Daylight	5.6	1.3	14	-	-	-
Night						
Total darkness	3.7	2.0	10	-	-	-
Blackout	3.6	1.8	8	-	-	-
Dusk	4.5	1.7	12	-	-	-
Dawn	4.9	1.6	12	-	-	-
Inside vehicle when not "buttoned up":						
Daylight	6.3	1.1	20	4.7	2.2	5
Night						
Total darkness	3.4	2.4	14	-	-	-
Blackout	3.0	1.8	11	-	-	-
Dusk	4.4	1.8	15	-	-	-
Dawn	4.8	1.7	15	-	-	-

The results are consistent with expectations considering the rainy, heavily overcast weather. It was apparently harder to see with the AO123(B) lens than with the AO23. The drawback to these data, however, is the extremely small sample size for the AO123(B) lens.

Soldiers at both sites assessed whether the lenses posed any problems in regard to visual characteristics. Table 18 shows the findings.

TABLE 18
PROBLEMS IN LENS VISUAL CHARACTERISTICS (%)

	AO123(B)		AO123(P)		AO23			
	Ft Polk N=36 Yes		Ft Polk N=7 Yes		Ft Polk N=33 Yes		Ft Devens N=20 Yes	
Problem	%	N	%	N	%	N	%	N
Depth perception	14	5	0	0	12	5	5	1
Distortion	14	5	14	1	18	6	10	2
Glare	11	4	29	2	9	3	0	0
Peripheral vision	44	16	43	3	39	13	45	9
Haze	31	11	43	3	23	8	-	-

The responses for the AO123(B) lens used at Ft. Devens numbered only one or two for each variable, so are not included here. The data shown for the AO123(P) lens are also few and are considered tentative.

The percentages reporting peripheral vision to be a problem are high across the board. Peripheral vision problems are primarily a goggle issue, not a lens issue.

The percentages of soldiers reporting haze to be a problem are higher than expected. According to what is known of the optical properties of the lenses, haze should not be a problem. It could be that the soldiers are using the word haze to express a fogging problem or the loss of visual acuity or transmittance.

Color Changes

Soldiers at both sites answered open-ended questions about whether they had trouble seeing particular objects or colors and what color changes they noticed.

The open-ended comments did not reveal any appreciable differences in the lenses. The responses covered a myriad of variables and situations. The following are generalizations derived from the data that apply to both AO lenses:

1) In respect to color, the expected differences emerged. The soldiers validated the difficulty of seeing reds, but there was no appreciable obliteration of that color - inside or outside of vehicles. There were a few specific references to red range displays and gauge markings being hard or impossible to see, but responses seemed consistent with findings for the static tests (see Section 10.)

2) Contrast is lowered and colors darken; it is harder to discriminate in tree lines and shaded/camouflaged areas.

Other Visual Problems

Some other factors that made seeing with goggles difficult are shown in Table 19.

TABLE 19
FACTORS CONTRIBUTING TO VISUAL DIFFICULTY

	Ft. Devens(N=20) % Yes	Ft. Polk(N=77) % Yes
Lenses fogged	90	35
Wearer not used to lenses	5	10
Wearer eyestrain	10	3

Although the percentages reporting a fogging problem are high for both sites, the Ft. Devens soldiers were wearing the lenses during very rainy weather throughout the test period. Soldiers at both sites, however, reported taking goggles off for that reason.

Fit and Comfort

Fit and comfort ratings (7=very good) from both sites are in Table 20.

TABLE 20
AVERAGE RATINGS FOR FIT AND COMFORT

	Ft. Polk (N=77)		Ft. Devens (N=16)	
	X	SD	X	SD
Fit	5.9	1.5	5.8	1.1
Comfort	5.7	1.6	5.6	1.4

Those individuals who rated either of those factors less than 4 (about 15% of the pooled rating groups) were asked to explain their ratings. The only recurring comment was that it was difficult to get a good seal. The ballistic lens is less flexible than the non-ballistic, which probably accounts for the comments.

Tinted Lens Substitute

Soldiers at both sites felt the lenses could substitute for the SWD tinted lenses. The frequencies of those responding yes to the question of whether they were dark enough are reported in Table 21. It also shows overall percentages: 95% of all (N=39) AO123(B) wearers and 82% of all (N=56) AO23 wearers thought the respective lenses could substitute for the tinted lenses. While all AO123(P) wearers felt similarly about that lens, the sample size was just from one site and too small to place full confidence in.

TABLE 21
SOLDIERS REPORTING LASER LENSES CAN SUBSTITUTE FOR TINTED

	AO123(B)	AO123(P)	AO23
Ft. Devens	N	N	N
YES	3	N/A	18
NO - not dark enough	1	N/A	2
NO - too dark	-	N/A	-
Total N	4		20
Ft. Polk			
YES	34	6	28
NO - not dark enough	1	-	5
NO - too dark	-	-	1
Total N	35	6	36
Yes (%)	95	100	82

CVC Helmet Compatibility

Soldiers at Ft. Devens felt the goggles' compatibility with the CVC helmet was not good; over half complained the goggle strap needs to be longer to fit over the helmet. As it is now, the goggles tend to pop off the helmet if the soldier tries to prop them there, or the soldier has to wear them around the neck and grope for the strap behind the head to put them back on - an especially difficult task when wearing gloves.

Reasons for Goggle Removal

Three-fourths of the Ft. Devens soldiers reported having to take off their goggles to perform job-related tasks. The reasons were mostly related to human factors issues. The goggles were not compatible with optical systems/sights and NBC masks. The lenses fogged. The goggles were also taken off to maximize visual performance when there was limited visibility and for situations that required total attention, such as searching tasks.

Conclusions

The AO123(B) and AO23 lenses did not hamper visual performance in bright daylight. In overcast weather, the AO23 performed very well, but the data are insufficient to make a statement about the AO123(B) in limited visibility.

Ratings from the Ft. Devens soldiers for the AO23 lens performance at dusk and dawn (also overcast) indicated adequate performance.

There were problems reported that were more a function of wearing a goggle than an inherent problem with the lens(es). Peripheral vision was restricted, and they were incompatible with optical devices and NBC masks. Fogging is the most serious issue; 90% complained at Ft. Devens, 35% at Ft. Polk, and it was a common reason at both sites for having to take off the goggles in order to see (Table 19).

TRACKED VEHICLE (STATIC) COMPATIBILITY TASKS

Armored vehicle crewmen from Ft. Polk and Ft. Devens participated in visual compatibility tasks conducted in static vehicles. Sample sizes differed considerably, and the vehicles at each site were different types, so the site findings are reported separately.

Objective

The tasks' objective was to determine if reduced light transmittance and color distortion through the lenses affect the soldiers' ability to read or see vehicle displays, controls, and readouts.

Ft. Polk

Test Procedures

Armor crewmen (N=179) from the 1st Brigade, 5th Armored Division assessed the instruments, indicators, and warning/caution lights at their stations for readability in "buttoned up" vehicles - the M3 Bradley Fighting Vehicle, and the M1 Abrams Tank. All adjustable display lights were turned to their brightest illumination for these tasks, and each subject performed the tasks with a randomized set of each of the following lenses: AO3; AO12; AO23; and AO123(B) or AO123(P). The subjects dark-adapted, but the adaptation times varied from 5 to 20 minutes. Illumination levels in the vehicles were dim, ranging from 0.2 to 10 foot candles, as measured by the Lightweight/SpotMate System 500.

The crewmen rated their ability to see each indicator or gauge on a four-point scale: (a) easy to see; (b) hard to see, but acceptable; (c) hard to see, not acceptable; and (d) can't see at all. The number of checklist items ranged from 5 to 12, depending on the job station. Subjects also responded to two global questions for each lens after each series of scaled questions: whether color(s) significantly changed and if the lens would affect their job performance. At the outset of their tasks they indicated whether or not they had any difficulty seeing any display with the naked eye.

The AO123(P) lens was introduced late in the testing, and there were few available, so there are far fewer data points for this lens then any other. There were also some missing data, and even vehicles of the same type had slight variances in the number of displays. Therefore, the number of data points can vary for any given vehicle or position.

The checklist of gauges and displays for each position and vehicle is in Appendix C. The colors involved were red, blue, green, yellow, white, and orange.

Results

It is difficult to present the ratings data in a manner that gives a good overall picture of lens performance. Since illumination levels and subject groups differ for each vehicle station, and the number and types of displays and readouts vary for each position, percentages can be deceptive. For instance, if a gunner with a 12-item checklist of displays rated all items negatively, that would add up to more poor ratings for that lens overall than if the driver, with a checklist of 5 items, rated everything negatively. Also, while the total number of poor ratings for a lens may be some indication of its performance, knowing that five different subjects said that a given gauge was impossible to read says more about the lens than if one subject said that five of his particular displays were impossible to read.

To try to offset these problems, the data presentation in Tables 22-26 consist not only of totals and percentages of the c and d ratings (c= hard to see, not acceptable; d= can't see at all), it also indicates any display that was rated by more than two subjects in the c and d categories. The percentages of soldiers who responded yes to the global questions about the lens affecting colors or the ability to do their jobs are also be reported for each lens, and soldier comments are summarized. For detailed breakdowns to those global questions, please see Appendix D.

Naked Eye

No subject reported any difficulty seeing displays or readouts with the naked eye.

TABLE 22
LENS AO3 TEST RESULTS FOR STATIC M3 BRADLEY AND M1 ABRAMS

AO3	Subject N	# of ratings	# of c/d ratings	% of c/d ratings
Abrams:				
driver	36	265	0	0
gunner	39	456	1	.2
tank commander	36	170	0	0
Bradley:				
driver	22	112	1	1
gunner	22	198	0	0
tank commander*	22	132	5	4
Lens totals	177	1333	7	.5

----

* 4 of 22 (18%) Bradley tank commanders gave c/d ratings for the ability to see their orange slope indicator circles.

Note:
Responses to global questions (N=175).
- 6% said colors were affected.
- 12% said their ability to do their jobs was affected. Over half of the 12% cited only human factors problems with the goggle, e.g. "couldn't get close to the reticle (cross-hairs), can't get close to sight."

TABLE 23
LENS AO123(P) TEST RESULTS FOR STATIC M3 BRADLEY AND M1 ABRAMS

AO123(P)	Subject N	# of ratings	# of c/d ratings	% of c/d ratings
Abrams:				
driver	4	31	0	0
gunner	5	59	2	3
tank commander	5	25	4	16
Bradley:				
driver	1	5	0	0
gunner	15	135	5	4
tank commander	15	90	10	11
	45	345	31	9

TABLE 23 (Con'd)

* 3 of 15 (20%) Bradley gunners rated ability to see the red reticle
in the c/d range.
* 3 of 15 (20%) Bradley tank commanders rated the orange azimuth indicator and pointer in the c/d range.
* 6 of 15 (40%) Bradley tank commanders rated the orange slope indicator circles in the c/d range.
* 3 of 5 (60%) of Abrams tank commanders rated the red reticle in the c/d range.

Note:
Responses to global questions (N=44).
- 60% reported that the lens affected colors.
- 40% reported their ability to do their job was affected, with most stating the lens made everything too dark.

TABLE 24
LENS AO12 TEST RESULTS FOR STATIC M3 BRADLEY AND M1 ABRAMS

AO12	Subject N	# of ratings	# of c/d ratings	% of c/d ratings
Abrams:				
driver	36	267	0	0
gunner	39	455	11	2
tank commander	36	170	4	2
Bradley:				
driver	22	112	1	1
gunner	22	198	2	1
tank commander	22	132	13	10
	177	1334	31	2

* 4 of 36 (11%) Abrams tank commanders rated the ability to see the red reticle in the c/d categories.
* 6 of 22 (27%) Bradley tank commanders rated the ability to see the orange
slope indicator circles in the c/d categories.

Note:
Responses to global questions (N=174).
- 37% reported color changes
- 21% reported their ability to do their jobs was affected. Job performance was affected by the lens, making it harder (darker) to see, with about one third also citing human factors problems with wearing the goggle.

TABLE 25
LENS AO23 TEST RESULTS FOR STATIC M3 BRADLEY AND M1 ABRAMS

AO23	Subject N	# of ratings	# of c/d ratings	% of c/d ratings
Abrams:				
driver	38	297	0	0
gunner	39	455	11	2
tank commander	36	170	16	9
Bradley:				
driver	22	111	1	1
gunner	22	198	1	.5
tank commander	22	132	10	8
	179	1363	34	2

* 11 of 28 (39%) Abrams gunners rated ability to see red reticle in the c/d categories (N differs from above because not all gunners rated reticle).
* 16 of 36 (44%) Abrams tank commanders rated ability to see red reticle in the c/d categories (N differs from above because not all tank commanders rated reticle).
* 3 of 22 (14%) Bradley tank commanders rated ability to see orange azimuth indicator and pointer in c/d categories.
* 4 of 22 (18%) Bradley tank commanders rated ability to see orange slope indicator circles in c/d categories.

Note:

Responses to global questions (N=178).

- 60% reported the lens affected color
- 31% said it affected ability to do their jobs. Complaints for this lens were that it made things darker, thus more difficult to see, with about one half also mentioning the human factors issue of not being able to get close to what they are viewing.

TABLE 26
LENS AO123(B) TEST RESULTS FOR STATIC M3 BRADLEY AND M1 ABRAMS

AO123(B)	Subject N	# of ratings	# of c/d ratings	% of c/d ratings
Abrams:				
driver	33	237	1	3
gunner	34	396	5	1
tank commander	31	145	5	3
Bradley:				
driver	21	66	2	2
gunner	7	63	0	0
tank commander	7	42	3	7
	133	949	16	2

*3 of 34 (9%) Abrams gunners rated the five display window numbers in the c/d categories.
* 4 of 31 (13%) Abrams tank commanders rated the red reticle in the c/d categories.
* 4 of 7 (57%) Bradley tank commanders rated the orange slope indicator circles in the c/d categories.

Note:
Responses to global questions (N=131).
- 38% stated colors were affected
- 26% reported ability to do the job was affected. The problem was that the lens made it too dark to see, and about two thirds also cited human factors issued associated with wearing goggles.

Color Changes

A chi-square analysis of the responses (which were pooled over vehicles and job stations) to the global question on color change showed that there was a significant difference in the response levels for the lenses (X^2 = 123.3, df = 4, p = .0000).

Post-hoc tests showed that the lenses divided roughly into three groups: AO3 is in a class by itself for affecting colors least, AO23 is the worst, and AO12, AO123(B) and AO123(P) are in the middle. (Although the percentages of soldiers reporting colors affected are the same for AO123(P) and AO23, the N for AO123(P) is smaller than for the other lenses, thus making it more difficult to show statistically significant differences.)

The most frequent color changes involved red becoming either darker or dimmer in conjunction with all lenses except lens A03, which is the only lens that does not block red wavelengths. Some reported that wearing lens A03 even made everything brighter, clearer and gauges easier to read. Another common color change observed by many soldiers for all lenses in varying degrees was that green turned blue.

On the whole, those wearing lenses A0123(P) and A012 reported that the red reticle and gauges were too dark to see (many gauges have a red component). Soldiers wearing lenses A023 and A0123(B) also generally described the reticle as either faded or darkened.

Job Performance

A chi-square analysis of the responses to whether a lens affected job performance showed that there was an effect (X^2 = 25.9, df = 4, p =.0000). Post-hoc tests showed few differences, however, among the lenses; A03 was reported to have affected job performance less than either A0123(P) or A023, but was no better than A012 or A0123(B). A0123(P), A012, A023 and A0123(B) were not dissimilar, statistically speaking.

Although anywhere from 12% to 40% of the soldiers reported that the respective lenses impacted on the ability to perform their jobs, they did not mean for the most part that they could not do their jobs, just that goggles made it more difficult. Soldiers by and large could see, and they knew what they were looking at. Even though colors can be darkened or altered, cues come from other sources as to the status of a gauge or other readout. For instance, if the red part of a gauge is darkened, soldiers still know an indicator is in the red zone because they know the location of the red zone relative to the other colors.

One thorny problem, however, is that of the reticle; too many failures were reported, especially for soldiers wearing A023. In the case of a reticle, one failure can be critical. The larger question is whether those who use sights have to be wearing the goggles. Sights are already hardened (laser protective), so at least for the gunner, there may be no issue. Many in the armor community feel that the gunner has little need for goggles in his position and many gunners stated that they could not shoot with the goggles anyway. The tank commanders are another matter. If they cannot see a reticle with goggles on, they would have to take them off and possibly risk exposure.

A definitive answer is required as to whether those looking through sights will have to be wearing the goggles. If they do, then more precise measurement as to how much vision is impaired is needed so that corrective measures can be taken if warranted.

The common human factors problem caused by the goggles was that they made it difficult to get near sights (making it even more difficult to see the reticle). This issue, too, will cease to have much significance if goggles are not required for this task.

The other display that bears further examination is the slope indicator circles in the Bradley. Although the numbers of c/d ratings were not as high as for the reticle, they appeared in the unacceptable rating categories for every lens.

One relevant point here is that any given color in any given type of vehicle, tracked or otherwise, can vary from vehicle to vehicle. Specifications for the manufacturer of tracked and other vehicles only cite the specific colors to be used for the gauges and displays, such as red, green or blue. They do not specify the boundaries of the wavelengths involved for any particular color. An example of what this fact means is that the red in a specific gauge in one Abrams can be a different shade of red than in another Abrams, and therefore, those two gauges may look somewhat different viewed through the same laser lens.

Ft. Devens

Test Procedures

Ten armor crewmen (three tank commanders, two gunners, and three drivers of the M60A3 and two M113A3 drivers) from the Ft. Devens population reported in Section 9.2 assessed various instruments, indicators, and warning/caution lights at their station for readability when the vehicles were "buttoned up." All adjustable display lights were turned to their brightest illumination for these tasks, and all subjects performed these tasks with each of the following lenses: AO3; AO12; AO23; and AO123(B). Each subject adapted to the dark for 10 minutes. Illumination levels in the vehicles, as measured by a Simpson Illumination Level Meter (Model 408-2), ranged from 0.5 to 25 foot-candles, with the M60 driver position having the least amount of light and the M60 tank commander the most.

The crewmen rated their ability to see each particular indicator or gauge on a four-point scale which read: (a) easy to see; (b) hard to see, but acceptable; (c) hard to see, not acceptable; and (d) can't see at all. They were also asked if any color(s) significantly changed and whether or not they felt the lens would affect their ability to do their job. They were asked a global question as to whether they had any difficulties seeing anything with the naked eye.

The static checklist for each position ranged from 4 gauges, displays, etc. for the M113 driver to 12 for the M60 gunner; the number of checklist items totalled across positions is 30, and the checklists are displayed in Appendix C. The total number of possible ratings for any one lens was 69. The colors involved were red, blue, green, yellow, white, and black.

Results

The data summary for each lens will be found in Tables 27-30, and each table includes the following for its respective lens: the sum total of unacceptable responses to the scale described above, i.e. the combined c and d ratings (c= hard to see, not acceptable; d= can't see at all); the number of crewmen who felt the colors changed significantly, soldier comments about color change, and the number of crewmen who felt their ability to do the job was affected.

Naked Eye

No one reported any difficulties performing any of the tasks with the naked eye.

TABLE 27
LENS AO12 TEST RESULTS FOR STATIC M60A3 AND M1113A3

AO12 (N=10) Five ratings out of 69 for this lens (7%) were in the c/d (unacceptable) range. The specific difficulties were:

M113 driver:	fuel gauge
M60 driver:	battery generator gauge.
	fuel gauge
	oil temperature light
M60 gunner:	azimuth indicator

	#Yes/N	(%)	Comments
Ability to do job affected?	3/10	30	One gunner said he would not wear lens while gunning.
Colors affected?	5/10	50	Altered green/yellows, reds darker.

TABLE 28
LENS AO23 TEST RESULTS FOR STATIC M60A3 AND M113A3

AO23 (N=10) There were no ratings in the c/d categories for this lens.

	#Yes/N	(%)	
Ability to do job affected?	2/10	20	Need to be closer to main gun sight (Tank Cdr). Lenses fog.

TABLE 28 CONT'D

Colors affected?	6/10	60	The only comments about lenses were that yellows went to white, objects became paler.

TABLE 29
LENS AO3 TEST RESULTS FOR STATIC M60A3 AND M1113A3

<u>AO3</u> (N=10). There were no ratings out of 69 in the c/d categories for this lens.

	#Yes/N	(%)	
Ability to do job affected?	2/10	20	Two tank commanders said yes because of the physical incompatibility of the goggle with sights, etc.
Colors affected?	0/10	0	

TABLE 30
LENS AO3 TEST RESULTS FOR STATIC M60A3 AND M1113A3

<u>AO123(B)</u> (N=10). The number of ratings in c/d categories totalled 8 out of a possible 69 (12%). Specific areas were:

M60 gunner: azimuth indicator
data control unit
data entry area
elevation scale

M60 driver: battery generator gauge
fuel gauge
oil temperature light

M113 driver: fuel gauge

	#Yes/N	(%)	
Ability to do job affected?	4/10	40	Too dark.
Colors affected?	6/10	60	Reds change.

Conclusions

Ft. Polk

No lens had a high failure rate as measured by overall percentages of c/d ratings. Almost the full range of displays at driver, gunner, and tank commander stations were visible in both the Bradley and Abrams tank in buttoned-up conditions. There were, however, two problems areas: the reticles in both vehicles and the slope indicator in the Bradley. Being able to see the reticle was especially problematic in the Abrams, with the AO23 apparently causing the greatest difficulty.

Anywhere from 12% (AO3 lens) to 40% [AO123(P) lens] of the soldiers reported the lenses affected the ability to do their jobs. However, these percentages apparently are not a strict function of lens performance, but are also influenced by human factors issues, such as the physical difficulty of getting close to sights.

Ft. Devens

These data do not indicate any serious problems. There were no c/d ratings for the AO3 and AO23. There were some c/d ratings for the AO12 and AO123(B), with the AO123(B) having the largest number of crewmen (4 out of 10) stating that this lens was so dark it affected their job performance. This result, again, does not mean that 40% could not do their jobs, only that it was made more difficult. This data set is small, but every subject had an opportunity to rate every lens, and no indicator or gauge was rated poorly by more than one subject for any lens.

No tank commander or gunner of these vehicles gave unacceptable ratings for their Thermal Channels, displays that have reticles. As the reticle in the Thermal Channels are not red, reticle problems are not an issue. Additionally, the Laser Range Finders, which also contain reticles, could not be opened. In any event, given the reticle problems uncovered at Ft. Polk, this situation should be investigated in the M60A3 and M113A3.

Generalization of Compatibility Data

The findings for this task are generalizable to at least two other families of military vehicles - trucks (specifically the 2-and-1/2-ton and 5-ton) and the High Mobility Multipurpose Wheeled Vehicle (HMMW-V). Natick personnel investigated the colors of the displays and gauges for these vehicles and found they had no colors that were not found in the tracked vehicles, and, of course, there is no reticle or slope indicator.

BLACKOUT LIGHTING TASK

The military family of vehicles has four small red lights at the rear of the vehicles - two on each side - that are turned on during blackout conditions so that vehicles can follow one another at proper distances. The lights "fuse" with distance and two red lights ("cat's eyes") are seen at distances around 180 feet on trucks and HMMW-Vs. If a driver of a vehicle sees four lights he/she is following too closely, and if only one light is seen, the distance between them is too great.

Objective

The tasks' objective is to determine if the lenses affect the ability to see a vehicle's "cats' eyes" during blackout conditions.

Test Procedures

This test was conducted at Ft. Polk on a clear, calm, warm night (approximately $80^{\circ}F$) on a range surrounded by trees in very dark conditions, 0.003 foot-candles as measured by a LightMate/Spotmate System 500 Photometer. Two vehicles were used - a HMMW-V and a 2-and-1/2 ton truck parked side-by-side about 6 feet apart with the blackout lights on. Subjects (N=24) dark-adapted for a minimum of 30 minutes, and were randomly assigned to one of two lines situated 180 feet from the vehicles.

Subjects were told to concern themselves only with the lights of the vehicle on their particular side (left or right). They were first asked the color and number of blackout lights they could see with the naked eye, and then asked the same questions through a sequence of four goggles. There was no change in the number or intensity of the lights. Each sequence contained AO3, AO23, AO12, and either AO123(B) or AO123(P). While the sequences of lenses were random within a set, the AO123(B) was restricted to one subject line and the AO123(P) was restricted to the other.

The data collectors worked in teams of two at each line of subjects - one recorded responses, and the other handed out goggles. They worked behind the subjects with penlights cupped in their hands to keep the area from being illuminated. Subjects were told to face forward at all times to maintain dark-adaptation.

Results

Data Handling

The first scan of the data showed that the responses from the soldiers who tested the goggle sequences with the AO123(B) lens could not be used due to a misunderstanding of test instructions. The analysis for the remaining 12 subjects follows.

Demographics

The 12 subjects all reported normal or corrected-to-normal vision. Normal color vision was assumed by virtue of MOS requirements. All were enlisted males between the ages 18-36 and ranging in rank from E-1 to E-4.

Table 31 shows subject (N=12) responses to questions as to number of lights seen and what their color was for each of four lenses and the naked eye.

TABLE 31

RESULTS OF BLACKOUT LIGHTS TASK

Condition	Number of lights seen	Perceived color
Naked Eye	2 (N=12)	Red (N=12)
AO3	2 (N=11) 4 (N=1)	Red (N=12)
AO23	1 (N=4) 2 (N=8)	Can't tell (N=2) Red or reddish (N=6) White (N=2) Green (N=1) Orange (N=1)
AO12	2 (N=11) 0 (N=1)	Reddish (N=11)
AO123(P)	0 (N=5) 1 (N=4) 2 (N=3)	Dark red (N=3) Off-white/orange/peach (N=3) Don't know (N=1)

Considering the pitch dark conditions, it is remarkable the lenses performed as well as they did. The wearers of AO3 and and AO12 lenses performed close to naked eye levels; the exceptions were that one person reported the wrong number of lights for AO3, one person couldn't see any lights for AO12, and the color of AO12 was affected somewhat.

The situation for the wearers of the other two lenses is more problematic. While AO23 had no failures as far as subjects not being able to see any lights at all, colors were distorted for about half of the subjects. For AO123(P) five subjects could see nothing at all, 4 out of 12 soldiers saw only one light instead of the two "cat's eyes," and there was color distortion for about half who could see the lights.

For all lenses, the number of lights wearers saw bore no apparent relationship to the perception of their colors. We assume that those who saw only one had the lens obliterate one of the lights (both lights in the vehicle may not have had the same brightness). We have no explanation for the subject who reported seeing four lights with AO3.

The better caliber of responses for the AO12 versus the AO23 appears to be a reversal of some of the daytime tasks but is consistent with the findings of the static tests. The reversal could be due to the different perceptual processes in reduced visibility conditions and/or contrast effects, or simply the function of small sample data distribution.

Conclusions

This task was created to probe the extent to which the lenses affect perception in the operational environment, and it did impart some worthwhile data, small sample size notwithstanding. None of the lenses made for complete dysfunction in blackout conditions - almost half of the AO123(P) users could see to some extent. Wearers of lens AO3 performed almost as well as the naked eye, and those with AO12 did remarkably well. Lens AO23 did not obliterate the blackout lights or color for all; one third could manage to see one light, and half the group could identify the light(s) they were seeing as red.

While it's gratifying that the lenses do not totally obliterate ability to see blackout lights, the effects of perceiving the color red as other than red are not known. That is, the question of whether the soldier will respond differently to hazard or safety warning lights that are no longer perceived as red should be further researched.

MAP READABILITY ASSESSMENT

Objective

This task was to determine if any of the lenses significantly affect map readability.

Test Procedures

Military map readability assessments were conducted with standard military installation maps - a 1:50,000 scale map and a 1:25,000 scale map. Subjects were given map reading tasks that involved identification of map feature names written in blue, brown (with a reddish cast), and red. If they could read the circled words, they were then asked to name the color of the words. For the red terrain feature identification task the red was an orange-red hue. Subjects were additionally asked to name what they perceived to be the color of red lines (roads) on one of the maps; in this case the red was a blue-red hue. The task set differed for each lens to avoid a learning situation, but the difficulty level was assumed to be the same, and the same colors were included in each task set. Subjects also rated each lens for how well they could read the map overall for navigation purposes.

The subjects were 14 Special Forces soldiers from the 10th Special Forces Group stationed at Ft. Devens. They ranged in rank from E-5 to E-8 and the average age was 30. Dvorine Color Plates were used to screen subjects for color blindness, and all subjects reported normal vision or vision corrected to 20/20.

All soldiers performed the tasks with the naked eye and four of the American Optical lenses in both daylight (100 foot-candles) dusk (0.5 foot-candles) illumination levels. They dark-adapted for 15 minutes for the dusk level. The test lenses were: AO3; AO12; AO23; AO123(B). The AO123(P) was not available at test time.

Illumination levels were measured by a Simpson Photometer (Model 408-2) at the table where the subjects sat. The light levels were contrived in the unit's dayroom using overhead fluorescent lights for the daytime condition and a small lamp with a 60-watt bulb for the dusk condition. The lamp was placed at the back of the room and the shade turned so that the light could not project directly at the subjects.

Results

Word Identification

Data in Table 32 show that all 14 soldiers could perform all or almost all word identification tasks successfully in both light conditions for most lenses and the naked eye, with the major exception of the AO123(B) lens in the dusk condition.

TABLE 32
FREQUENCIES OF TERRAIN IDENTIFICATION FAILURES (N=14)

	DAYLIGHT FAILURES Word Colors			DUSK FAILURES Word Colors		
	Blue	Brown	Red	Blue	Brown	Red
Naked Eye	0	0	0	0	0	0
AO3	0	0	0	0	0	1
AO12	0	0	0	1	2	1
AO23	0	0	0	1	0	0
AO123(B)	2	0	0	5	7	4

The only task failures in the daytime condition occurred when wearing the AO123(B), with 2 out of 14 soldiers failing to identify the words printed in blue.

In the dusk condition the two stand-outs are the AO12 and AO123(B), with the latter performing appreciably worse than the former. While the AO12 does not have near as many failures as the AO123(B), it did have a failure or two in each color category.

Color Naming

For the daytime condition there was no appreciable color distortion reported when wearing the AO3 or AO23 lens, and most identified the colors in one-word terms: red (regardless of whether the hue was blue or orange), blue, and brown. When wearing the AO123(B) or AO12 lenses about half the soldiers identified the reds, both the blue-red and the orange-red, as other hues or colors, such as dark red, brown, orange, and red orange, with no appreciable differences in either hue group.

For the dusk condition, the same situation existed for color distortion as in the daytime condition and approximately to the same degree for all lenses, with two exceptions. Wearers of AO23 began to show some distortion as well; about half the soldiers named the color either orange or reddish-brown. Also, two inappropriate answers were given for red when wearing the AO123(B): grey and blue-brown.

There were only three cases in which a subject could not identify the color of some words at all; the colors apparently were obliterated in such a way that they failed to have contrast with their backgrounds. The cases were all in the dusk condition: two for the AO12 (one brown, one red), and one for the AO123(B) (brown). In any event, there were far more cases of not being able to read words than there were failures to distinguish that the words still contrasted to some extent with their background.

There are also a few cases in the dusk condition with AO12 and AO123(B) where brown was mislabelled as dark red or black. No inappropriate labels were applied to the color blue for any lens under any condition except for AO123(B) at dusk, where one soldier called it gray and another called it black.

Soldiers familiar with military maps know what color different types of terrain features are supposed to be (the different terrain features have designated colors), so we do not know how much their naming of a color was influenced by what they knew to be the case. Soldiers could have also given different names to the same color as they could have learned different names for the same color, or perhaps some were not as color sensitive as others.

The soldiers also rated the overall difficulty of reading the the map for navigational purposes for each lens in each condition. The scale used and the findings are in Table 33.

TABLE 33
MEAN RATINGS FOR ABILITY TO READ MAP OVERALL

1 = Very easy to read
2 = Somewhat difficult to read
3 = Moderately difficult to read
4 = Very difficult to read
5 = Can't read

	Day (100 foot-candles)		Dusk (.50 foot-candles)	
	$\bar{X}$	SD	$\bar{X}$	SD
Naked eye	1.0	.0	1.0	.0
AO3	1.0	.0	1.1	.4
AO12	1.1	.4	2.4	1.0
AO23	1.0	.0	1.4	.8
AO123(B)	1.1	.4	2.9	1.2

For the daytime condition the ratings were perfect or almost perfect for all lenses and the naked eye. There was no point to any sophisticated analyses on the daylight data; the numbers speak for themselves. Moreover, inferential analyses are inappropriate when there is no variance. In this case, there were three means with no variance and the other two means and variances were equal. For the dusk condition, however, the ratings show some definite differences. A MANOVA conducted on these data (except for the naked eye, which had no variance) showed an effect for type of lens (F=12.03; df=3,52; p=.000). The results of the post-hoc SNK test on the means are in Table 34.

TABLE 34 (N=14)
EFFECT OF LENS ON ABILITY TO USE MAP TO
NAVIGATE IN DUSK CONDITION:
RESULTS OF THE STUDENT-NEWMAN-KEULS PROCEDURE
(1=VERY EASY; 5=CAN'T READ)

Lens	AO3	AO23	AO12	AO123(B)
Mean Rating	1.1	1.4	2.4	2.9

There were no significant differences in the pairs of underlined lenses. Any other combinations of two means would be significantly different. Subject's ratings indicate that it is significantly easier to use a map with AO3 or AO23 than it is with AO12 or AO123(B) in a dusk condition.

Conclusions

None of the four lenses presents any difficulty with map reading in the daylight condition; they all perform about as well as the naked eye. Any color distortion that exists does not affect map feature word identification.

In the dusk condition, the AO3 and AO23 perform very well, with AO3 virtually the same as the naked eye and AO23 very close behind it. AO12 and AO123(B) show statistically worse ratings of overall ability to read maps. There were also task failures across the color range, with a 38% failure rate for the AO123(B) and 10% for the AO12.

SAFETY

Laboratory testing sponsored by Natick showed all the candidate lenses meet requirements for ballistic and laser protection; these issues were not addressed in field tests. Our field data (as indicated in Table 2) for the AO lenses, however, do not suggest any safety problems relating to reduced transmittance and color distortion other than what was assumed before the testing. That means wear of the lenses should be consistent with wear policy governing the use of ordinary sunglasses; any decision to wear them when visibility is limited is dependent on user discretion and/or the optical density of the lenses at hand.

DURABILITY

We cannot validly assess lens durability. The maximum time any lens was used was only 72 hours, and the only ones receiving that much usage were the AO23 and AO123(B) lenses used at Ft. Devens during a weekend exercise. In all test scenarios except the Ft. Devens exercise, data collectors were controlling lens usage, and so the lenses were not receiving the normal abuse they would be getting in the field. While the lenses used in the Ft. Devens field exercise did show some degree of scratching, only two sets were scratched badly enough to be excluded from any subsequent tests. Even those lenses, however, could still be considered "functional" if necessary. (A general complaint that soldiers have of the standard goggles, which has been documented by in-house field surveys, is that the lenses scratch easily.[8])

The Gentex lenses were not used except for the Farnsworth-Munsell 100-Hue Test. Usage for this test averaged 5 hours per lens. During that time however, two lenses were taken out of the test because of delamination.

DISCUSSION

Assuming that the Farnsworth-Munsell 100-Hue Test shows both the effects of lens transmittance levels as well as color distortions, the field test data are relatively consistent with the Farnsworth-Munsell test results. When results are not consistent, however, it appears they can be explained by factors peculiar to the test situation. Among these factors are the discrimination power of the eye, properties of light and color, and contrast effects.

We found that our field tests showed minimal ill effects on performance for any lens in daylight illumination. The Farnsworth-Munsell tests, showed that AO12 and AO123 were statistically poorer performers than the other lenses for the daylight condition. However, average error rates for all lenses still fell in normative bounds.

Similarly, the Farnsworth-Munsell test showed no distinct color polarization pattern for any of the AO lenses in the daylight condition. In the field tests, however, the soldiers verified the expected distortion in some of the red and green spectra. While this may seem somewhat contradictory, the soldiers did not feel the distortion to be of serious consequence, and it is often assumed that the eye can discriminate changes in color that go beyond a particular test's ability to detect them.

The reduced visibility field test results are also generally in line with the Farnsworth-Munsell results. In the deep dusk condition of the Farnsworth-Munsell, the best lens performer was

the A03, with the A023 ranking second, and A012 and the A0123 sharing the third rank. In this condition all average error rates exceed the norm and there is color polarization in all cases (to include the naked eye condition).

The target detection task, which had some reduced visibility, but nowhere near the deep dusk condition of the Farnsworth-Munsell, showed the A03 and A023 on par with the naked eye, and A012 and A0123 showing impaired (and similar) performance. The reduced transmittance levels do not have much practical import in full daylight, but do with decreasing levels of illumination.

The map reading task in reduced illumination also revealed the same order of lenses when soldiers rated their ability to navigate while wearing them: the naked eye, A03, A023 were all on par, with the A012 and A0123 in a tier below.

Static vehicle testing showed the A03 to be the best performer as far as how the soldiers felt they could do their job while wearing the various lenses. A012 and A0123 were again found to be significantly worse than A03, and in this case A023 ranked with the latter two - an apparent inconsistency. However, the A023 lens' tint is green, and the soldiers had problems seeing their vehicles' red reticles and orange slope detectors with it. A green filter (lens) will affect the ability to see red, and this will be much more pronounced in reduced visibility conditions because of reduced contrast effects as well as the eye's decreased ability to perceive red as green. The A0123 lens is brown and the reticle was much more easily preceived. In this reduced visibility case, the color of the lens was more of a problem than its level of transmittance.

The tint phenomenon is also observed in the blackout task, in which the soldiers were looking at red lights. Here A012 seems to perform almost as well as the naked eye and A03, while the green-tinted A023 seems to be the worst performer (A0123B was not in this test). The effects of contrast and tint probably account for the good performance of the A012.

As anticipated, the laboratory data serve more as a reference for the field data than a prediction of field performance. There are too many variables involved in lens field testing for any one test to serve as a predictor of specific types of performance. While more than one laboratory test is certainly indicated, manpower and dollars in today's economy don't often allow the luxury of extensive test batteries in both the laboratory and the field.

Our goals in future investigations are two-fold. The first is to refine some of the tests we have. All those conducted served well in their role of specific mission performance indicators, but the tests need some fine tuning in the way some performance is measured. There is a need to add to the variables explored. Some

specific needs are apparent in the map reading, static, and blackout tasks.

One way the map reading test can be improved is to have the soldiers name the colors they are perceiving referenced against a set of specific color names or a color wheel, instead of allowing them to use their individual color vocabularies.

Some type of index needs to be derived for measuring lens performance in the static vehicle task. Not only do the vehicle stations differ in the number of readouts and gauges, which can distort percentage error rates, but also there is an issue of some readouts being more critical than others for mission performance. These need to be identified and weighted appropriately.

The blackout test can be improved by investigating light fusion thresholds more rigorously so that subject distance from the light source can be better determined, and a more precise measure of soldier ability to detect the light(s) is needed.

Now that these tests have surfaced some problem areas, especially in reduced visibility conditions, variables need to be added that probe issues, such as the ability to detect camouflaged items and the more critical vehicle readouts and displays.

The second goal is to be able to translate some laboratory test(s) results into practical performance terms. For instance, can future testing find a meaningful correlation between laboratory acuity test scores and a soldier performance on a firing range? While field testing will always be needed, large-scale testing is usually prohibited by economic factors. We could be more judicious about the nature of the field testing we do and more confident in our product decisions if we felt that we had some reliable performance indicators that help fill the gaps left with limited field testing opportunities.

SUMMARY/CONCLUSIONS

Since the Gentex lenses were dropped from consideration because of their failure to meet technical requirements, and also because they were not included in any test except the Farnsworth-Munsell 100-Hue Test, they will not be discussed in this section. Our discussion will be confined to American Optical lenses, with the exception of AO123(P); that lens did not garner enough field data to warrant any conclusive statements.

Since each of the six data sets has a separate conclusion in its particular section, the main objective at this juncture is to present an overview of the findings and some general recommendations for wear.

Daytime, AO3; AO12; AO23; AO123(B)

Farnsworth-Munsell 100-Hue	All four AO lenses showed error scores in normal ranges and no obvious clustering of errors for any color, indicating that any loss in color discrimination falls in normal ranges.
Target Detection Ability	There were no differences in any of the four AO lenses in respect to a wearer's ability to see a target at 50m, 100m, 250m, and 300m. Any worsening of target detection was a function of the distance of the target.
Map Reading Tasks	None of the 4 lenses was thought to present a problem for a wearer's overall navigation. Soldiers with AO123(B), however, did show 2 out of 14 task failures for terrain features printed in blue. AO12 and AO123(B) did distort color to some extent.
Operational Use	Only AO23 and AO123(B) were used operationally. Both performed well in daytime and were considered suitable for field use and tactical situations. Soldier comments documented the expected degradation of colors and reduced contrast. Red is generally darkened and it is harder to discriminate greens against tree lines and camouflaged areas. There were some significant problems, however, that were not due to adding laser protection, i.e., the lenses fogged and peripheral vision is affected. Also about half the soldiers felt the goggles were not compatible with the CVC helmet.

Reduced visibility, AO3; AO12; AO23; AO123(B)

Farnsworth-Munsell 100-Hue	In this deep dusk condition all average error scores exceeded normal error bounds (as did the score for the naked eye), which indicated varying degrees of loss of color discrimination ability. For the most part, the lenses showed a progression of statistically significant differences, with the exception that there was no difference between AO12 and AO123. Proceeding from best average error score to worst, they were: AO3; AO23; AO12; and AO123.
Target Detection	During sundown/dusk conditions, ratings for the ability to detect targets with AO3 and AO23 did not differ statistically from the naked eye. AO12 and AO123 were significantly worse, showing about one scale point worse than the other lenses. AO12 and AO123 did not differ significantly from each other.
Map Reading Tasks	In a deep dusk condition, there was a 38% task failure rate for the AO123(B) lens and a 10% rate for the AO12. The other lenses had no more than an isolated task failure. The color distortion for AO123(B) and AO12 is not much worse than daytime. However, soldiers report distortion for the AO23 lens as well for this illumination condition. There is no overall problem using the map for navigation wearing the AO3 or AO23. The task is significantly more difficult with the AO12 and AO123(B).
Blackout Light Task	In pitch dark conditions wearers of AO3 and AO12 performed close to naked eye levels, i.e., seeing the correct number of lights and perceiving them as red. About one-half of the soldiers wearing the AO23 lens did not perceive the

blackout lights as red, and about one-third saw only one light instead of two "cats' eyes." There are no data for AO123(B).

Operational Use	There are no data for AO123(B). AO23 appears to perform adequately at dusk and dawn.
Static Tests	In buttoned-up M1 Abrams tanks and M3 Bradleys there were very small percentages of failures or extreme difficulty in seeing gauges and display at the various vehicle stations when the whole vast array is taken into account. However, there was a definite overall problem in seeing the reticles in both vehicles and the orange slope indicator in the Bradley. The reticle problem is especially pronounced in the Abrams tank, with the AO23 lens apparently presenting the most difficulty.

Depending on the type of lens, anywhere from 12% (AO3) to 31% (AO23) of the soldiers stated the ability to do their jobs was affected. Statistical analyses showed AO3 to be a better performer, and there were no differences among the other three.

Even though a percentage as high as 40 seems rather drastic, it must be remembered that these soldiers were not saying they could not do their jobs, just that the tasks became more difficult. These percentages were also influenced across the board by human factors problems associated with wearing a goggle, such as not being able to get close to sights.

Daytime

There were no adverse effects that would preclude use of any of the four lenses summarized above during daytime illumination levels.

Reduced Visibility

The ideal lens for reduced visibility condition is the A03 while the worst appears to be the A0123(B). The results for A012 and A023 which give more protection than A03 are somewhat inconsistent. The reasons for this phenomenon are not clear. It could be a result of the specific level of illumination, background contrasts, statistical anomalies, or interactions of those conditions.

In any event, the A023 was better than A012 and A0123(B) in target detection and map navigation. It also seemed to be adequate for use operationally during dusk and dawn. Although the static test results were not impressive for the A023 lens considering the reticle issue, it was statistically no worse than the A012 and A0123(B) in response to a question about its effect on the overall ability to do the job.

While A012 was a surprisingly good performer in the blackout lighting task, and no worse than the A023 in its effect on ability to do the job, it performed less well than the A023 on the Farnsworth-Munsell, Target Detection and Map Reading tests.

RECOMMENDATIONS

While no lens appears to present any significant problem for daytime wear, we recommend that A0123(B) should not be used during periods of reduced visibility, and feel that A023 can be worn at user's discretion during periods of limited visibility. Overall, neither lens appears to distort colors in any way that would seriously affect job performance or be unduly hazardous when wear is consistent with such usage.

The exception, however, is in use of the reticle in the Abrams and possibly the slope indicator in the Bradley. These situations need to be investigated further, especially with the A023 lens.

The human factors issues that make lens wear a problem need to be addressed in the program dedicated to redesign of the SWD goggle. If a soldier feels compelled to remove a goggle because of a human factors problem, the adequacy of laser protection becomes irrelevant.

Finally, the policy of lens wear at the different tracked vehicle stations should be defined. If some positions do not require their wear, then there may be some mitigation to the problems observed in the static tests.

REFERENCES

1. Biechler, CPT Dwight A., (1979). Concept evaluation of Goggles, Sun, Wind, Dust (product improved). Fort Knox, KY: U.S. Army Armor and Engineer Board.
2. Deter, CPT Daniel E., (1974). Development test II (service phase) of Goggles, Sun, Wind, and Dust. Fort Knox, KY: U.S. Army Armor and Engineer Board.
3. Randall, R. Bradley, (1977). Development of preliminary sizing criteria for improved Goggles, Sun, Wind and Dust (technical note 6-77). Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory.
4. Ruple, MAJ Charles W., Mayhew, William M. & Machnic, SFC Jerry L., (1977). Fort Knox, KY: U.S. Army Armor and Engineer Board.
5. Farnsworth, Dean (1957). The Farnsworth-Munsell 100-Hue Test for the examination of color discrimination, Manual. Baltimore, MD: Munsell Color Company.
6. Committee on Vision, (1981). Procedures for testing color vision: Report of working group 41. Assembly of Behavioral and Social Sciences National Research Council. Washington, D.C.: National Academy Press.
7. U.S. Department of Defense. Military Specification MIL-G-43914, Goggles, Sun, Wind & Dust, Philadelphia, Standardization Document Order Desk,* 1974, revision E, 1990.
8. Operational Forces Interface Group: Summary of Evaluated Equipment, 1985 Thru 1989, 12 February 1990, Behavioral Sciences Division, Soldier Science Directorate, U.S. Army Natick Research Development and Engineering Center

---

*700 Robbin Avenue, Building 4D, Philadelphia, PA 19111-5094

APPENDIX A
AVIATOR GOGGLE TESTING SUMMARY

References:

1. U.S. Army Aviation Development Test Activity, Test Plan, HGU-56/P Aircrew Integrated Helmet System (AIHS) and SPH-4 Helmet Laser Protective Device (LPD), TECOM Project No. 4-EI-515-AHS-001, dtd 23 March 1988

2. U.S. Army Aviation Development Test Activity, Test Report, HGU-56/P Aircrew Integrated Helmet System (AIHS) and SPH-4 Helmet Laser Protective Device (LPD), TECOM Project No. 4-EI-515-AHS-001, dtd 21 Sep 1988

Seventeen HGU-56/P and 15 SPH-4 laser protective devices (LPD) along with two types of laser protective spectacles were tested. The HGU-56/P and SPH-4 LPDs are visors which are installed in aviator helmet systems and provide aviators eye protection against fixed, low-powered lasers. The HGU-56/P LPDs utilize holograph and absorber laser filter technologies, while the SPH-4 LPDs utilize absorber technology. The LPDs were separated into nine candidate groups differing by type and protective frequency range. The nine groups are as follows: A2/3, A1/2/3, G3, G1/2, G1/2a, G2/3, G1/2/3, Spectacles 2/3 and Spectacles 1/2/3. Table A-1 shows the Manufacturers, frequency range identification and color of each group of lenses and spectacles.

Table A-1.

Manufacturer Item Name	Quantity	Test Item Serial Number	USAAVNDTA Identification No.	Color
American Optical				
HGU-56/P LPD	14	A028-A041	A2/3	Blue/Green
HGU-56/P LPD	3	A01, A02, A08	A1/2/3	Rose
Gentex Corporation				
SPH-4 LPD	3	1I, 1J, 1K	G3	Lime
SPH-4 LPD	3	2A, 2B, 2D	G2/3	Green
SPH-4 LPD	3	2O, 2Q, 2R	G1/2	Light Amber

Table A-1 Cont'd

SPH-4 LPD Amber	3	2I, 2J, 2K	G1/2a	Light
SPH-4 LPD	3	3I, 3J, 3K	G1/2/3	Amber
<u>American Optical</u>				
Spectacles	2	SA01, SA02	2/3	Blue/Green
Spectacles	1	-	1/2/3	N/A

Testing was performed to assess depth perception, visual acuity, map readability, cockpit compatibility (static) and In-Flight Assessment. Along with this testing, questionnaires were administered to the test participants. Results were:

a. Depth Perception. In order to determine if the candidate LPDs and Spectacles degraded depth perception, aviators were tested using an internally illuminated (7 foot-candles) Howard-Dolman depth perception device. All of the LPDs and Spectacles (except LPD A2/3) were tested, along with a standard tinted visor, a standard clear visor and no visor. As a result of this analysis, it was found that no significant differences existed among the 11 test conditions with respect to depth perception.

b. Visual Acuity (Night and Day). Visual acuity through the LPDs was measured using a Landolt C-ring test. The test was conducted using target illumination levels of 3.3×10^{-3} fc and 4.0×10^{3} fc. Each participant was tested while wearing his issued SPH-4 helmet, the AN/AVS-6 and the AN/PVS-5 night vision goggle (NVG), and the following: each of the eight candidate LPDs (except LPD A2/3), the standard tinted visor (4.0×10^{3} fc only), the standard clear visor, and no visor. During the daylight conditions (4.0×10^{3} fc) no significant differences existed among the 11 test conditions with respect to visual acuity. However, during the night conditions (3.3×10^{-3} fc)

significant differences did exist among the different lens conditions. Night visual acuity with the standard clear visor or no visor was significantly better than with all LPDs. Among the candidate LPDs visors G2/3, G3, and spectacles 2/3 were significantly better than visor A 1/2/3. Also, night visual acuity was significantly better with spectacles 2/3 than with spectacles 1/2/3 and G11/2a.

c. Map readability. Both day and night laboratory map readability trials were conducted using eleven different shaded production maps for the day trials and one 1:50,000 scale map for the night trials. Daytime map illumination level was 4.0×10^3 fc, while night illumination levels was adjusted until the participant felt he could use the map for navigation purposes. These trials were conducted while wearing each of the eight candidate LPDs (except LPD A2/3), a standard clear visor, a standard tinted visor (day only), and no visor. No significant differences were found as a result of the daytime trials; however, significant differences did result from the night trials. Visor A1/2/3 required significantly higher illumination levels for map readability than visor G3, the standard clear visor, or no visor. There were no significant differences among the other test conditions.

d. Cockpit Compatibility Assessment (Static Aircraft). Cockpit compatibility assessments were performed with the candidate LPDs in the UH-1H, CH-47D, AH-1F, OH-58D, UH-60A, and AH-64A pilot and copilot/gunner/observer crewstations under both day and night conditions. Cockpit instruments and displays were assessed for readability, both with and without the candidate LPDs for comparison purposes. Emphasis was placed on detectability of master caution and warning indicators. This testing was performed during daylight conditions (10,000 fc) and nighttime conditions (a darkened hangar, with the participant adjusting the lighting level).

As a result of this testing, cockpit compatibility problems were encountered during both day and night conditions with each candidate LPD. During the daytime conditions, readability problems with the red digital display on the radar altimeter were experienced with all candidate LPDs in the CH-47 and/or AH-1 aircraft. Also, problems were identified with visibility of activated caution/warning indications. Nighttime conditions also presented compatibility problems, such as glare and limited visibility outside the aircraft.

e. In-Flight Assessment. Five of the nine candidate LPDs (visors G2/3, G1/2a, G1/2/3, A1/2/3, and A2/3) were approved for in-flight user, cockpit, and flight compatibility testing. IFR flight assessments were accomplished during day, twilight and night conditions. Emphasis of this testing was placed on readability of cockpit instruments/displays and caution/warning indicators. Comments were recorded during the assessment, as well as questionnaires being administered after the test. Results of this testing indicated that with respect to visibility outside the aircraft during the day, all LPDs flight tested were satisfactory. However, Visors G1/2a, G1/2/3, A1/2/3 and G1/2 (night only) were found to be unsatisfactory due to illegibility of essential IFR flight instruments during both day and night. Spectacles 1/2/3 were unsatisfactory due to distracting lens reflections which caused visual degradation during day and were questionable due to lens reflections during the night IFR.

Visors G2/3, A2/3, and A1/2a were considered acceptable for dusk flight by the majority of the participants, whereas visors A1/2/3 and G1/2/3 were considered too dark for dusk flight. Adverse glare was reported at dusk with visor G1/2/3 due to the necessity of adjusting cockpit lighting to maximum intensity for instrument/display readability.

During night IFR, problems with visual acquisition of red lights were reported for all five LPDs flight tested. Also, incompatibility with blue-green cockpit lighting was identified with G1/2a, G1/2/3 and A1/2/3.

As a result of the above testing and questionnaires, the following were concluded:

a. Visors G3, G2/3, G1/2, and spectacles 2/3 were considered acceptable for day instrument flight rule (IFR) flight.

b. No visual degradation was reported with spectacles 2/3 while flying with AN/AVS-6 goggles in UH-60 and AH-1S aircraft.

c. Visors G1/2a, G1/2/3, and A1/2/3 were considered to be unsafe for night visual flight rule (VFR) flight due to pilots' inability to identify external cues.

d. LPDs G1/2, G1/2a, G1/2/3, A1/2/3 and spectacles 1/2/3 were considered unsafe for night IFR flight due to pilots' inability to read essential flight instruments and avionics. Pilots also experienced difficulty in reading instruments with G1/2/3 and A1/2/3 during day IFR flight.

e. Visual degradation caused by lens reflections and adverse glare was reported with spectacles 1/2/3.

f. Problems with visual acquisition of red lighting at night were reported with LPDs G2/3, G1/2a, G1/2/3, A1/2/3, and A2/3.

g. Difficulty in seeing activated caution/warning/advisory indicators in sunlight was reported with visors G1/2/3, A2/3, and spectacles 1/2/3.

APPENDIX B

THE FARNSWORTH-MUNSELL 100-HUE TEST

for the Examination of

Color Discrimination*

PURPOSE

The Farnsworth-Munsell 100-Hue Test offers a simple method for testing color discrimination. It yields data which can be applied to many psychological and industrial problems in color vision. Its primary uses are, first, to separate persons with normal color vision into classes of superior, average and low color discrimination, and second, to measure the zones of color confusion.

MATERIALS

The materials include four wooden cases, a total of 93 plastic caps in which the colors are mounted, and the score sheets. Each case consists of two hinged panels which enclose one-fourth of 85 numbered, removable color caps. (Two caps are repeated and fixed as pilot colors at either end of one panel in each case, making a total of 93 caps.) The scoring sheets contain four rows of numbers corresponding to the numbers on the backs of the removable color caps in the four cases, a scoring diagram, and spaces for recording other customary data.

ADMINISTRATION

Instruct the subject as follows:

"The object of the test is to arrange the caps in order according to color. Please transfer them from this panel (indicate) to this panel (indicate) and place them so they form a regular color series between these two caps (indicate). It should take you about two minutes per panel. However, accuracy is more important than speed - so you will be told when the two minutes are up but the panel will not be taken away from you. Arrange them as best you can, but don't dawdle. Do you understand? Begin."

----

*An abbreviated version of the instruction manual was reproduced with special permission of the publisher, the Munsell Color Company, Inc., Baltimore, MD 21218, manual by Dean Farnsworth, Copyright 1957.

RECORDING DATA

Space is allowed on each data sheet for recording two trials, a test and retest. Where the numbers are found to be in correct order, draw a line above (on retest, below) the printed numbers. When they are not in serial order, record them in the order in which they are arranged by the examinee.

After the arrangement of the caps has been recorded, transfer them to the opposite panel, rearranging them in random order. Then close the case and turn it over. It is now ready for future testing.

SCORING AND DRAWING THE PATTERN

If but a few transpositions are made, the errors can be counted at once. It is not even necessary to draw the pattern. Count 4 for each 2-cap transposition and 8 for each 3-cap transposition.

If there are many errors it will be necessary to draw a pattern consisting of the scores for each cap. The score for a cap is the sum of the differences between the number of that cap and the numbers of the caps adjacent to it.

The inner circle of numbers on the chart corresponds to the number of the caps. Take the first (inside) dotted line as a score of 2 (the lowest possible); the heavy dotted circles will be at 5 and at 10. Mark the score for each cap on the radial line carrying its number. Connect the points by lines of different colors for each test. An average can be found graphically by connecting points intermediate between the points on each radial line for each test.

The total error score is obtained by summing the errors on each radial line, now counting the inner circle as zero. (This has the effect of subtracting 2 from each individual score so that perfect sequences appear as zero on the pattern and count as zero on the total error score.) Refer to Figure B-1.

INTERPRETATION

After the pattern has been plotted, there are various methods of interpreting the results, depending upon the information wanted from the test. Norms are given below for several common groups: superior discrimination, average and low discrimination, and for types of color defectiveness ("color blindness").

AVERAGE DISCRIMINATION

A typical test and retest pattern for an average normal is illustrated in Figure B-2. Seven 2-cap transpositions were made on the first test, four 2-cap and one 3-cap transposition on the retest, resulting in total error scores of 28 and 24, respectively.

About 68% of the population (exclusive of color defectives) make a total error score of between 20 and 100 on first tests. This may be taken as the range of normal competence for color discrimination.

SUPERIOR DISCRIMINATION

About 16% of the population (exclusive of color defectives) has been found to make 0 to 4 transpositions on first test, or total error scores of zero to 16. This may be taken as the range of superior competence for color discrimination.

LOW DISCRIMINATION

About 16% of the population (exclusive of color defectives) has been found to make total error scores of more than 100. The first retest may show improvement but further retests do not materially affect the score. Repeated retests reveal no region of large maximum or minimum sensitivity as is found in color defective patterns. An example of a low discrimination pattern is given in Figure B-3.

Error scores by normals often exceed that of many color defectives, yet these individuals do not exhibit color blind indications on this test, on anomaloscopes, or on pseudo-isochromatic tests. Such scores point up the fact that the 100-Hue Test is, as described, a test of color aptitude or ability to make color discriminations. General color discrimination is independent of color defectiveness so it is possible for some normals to have poorer color discrimination than some color defectives. Color normals may have good or poor color discrimination; color defectives may have good or poor color discrimination.

DEFECTIVE COLOR VISION

The pattern of color defectiveness is identified by bi-polarity, a clustering of maximum errors in two regions which are nearly opposite. The regions in which the errors are made can be used to identify the type of color defectiveness if this is also of interest. Typical examples of patterns made by types of color-defective persons are shown in Figures B-4, B-5 and B-6. Each of these cases exhibits a severe degree of defect; moderate cases show small "bulges" and lower total error scores; mild cases with good color discrimination may show no "bulge" and cannot be identified by this test. The position of the mid-points of the errors in the pattern (the middle of the "bulges") will identify the type. (The mid-points can be found roughly by inspection or accurately by the method described earlier).

The distribution of mid-points from 112 tests is plotted in Figure B-7. It shows the scatter to be expected from single test scores. Diagnosis of color defect should be made upon the average of at least two tests. The average of the mid points of several tests will always fall within the ranges stated above. Some mildly defective individuals will be found whose discrimination or aptitude is so high that no amount of retesting will elicit a color defective pattern.

The significance of a pattern can be described by reference to Figure B-5. The errors lie chiefly between blue and purple-bluepurple, and between yellow-red and yellow-green-yellow. Research has shown that any series of colors parallel to the above series will also be confused. For instance, there will be low aptitude for discriminating red-purple, green and gray (in the middle of the diagram), low aptitude for discriminating purple from greenish-blue, or red from yellowish-green. On the other hand, the ability to distinguish colors in a green-yellow to blue series or to distinguish yellows from grays will be as good as that of most normals (because these series lie in lines which are parallel to the series in which he makes few or no errors).

As the terms "color defectiveness" and "color blindness" have been employed in literature, they indicate a type of systematic color imbalance, that is to say, certain series of colors are less well discriminated than other series of colors. Pseudo-isochromatic tests are designed to test color imbalance, but not to test color discrimination. The 100-hue pattern will indicate the type of the imbalance, the color zones of best and poorest perception and the degree of color discrimination in those zones as compared to normals.

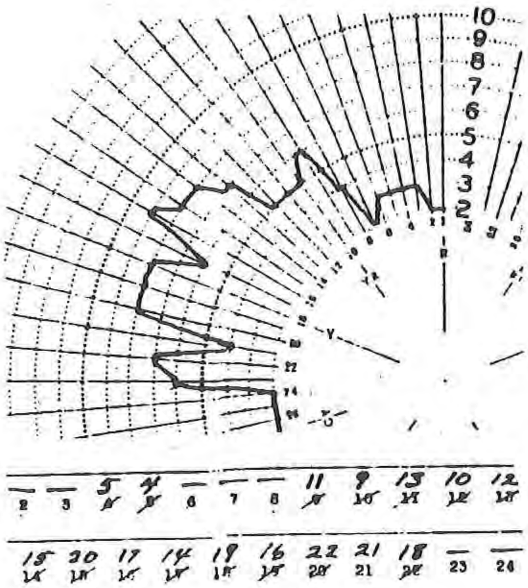

Figure B-1
Section of a subject's profile
illustrating how error scores
are plotted

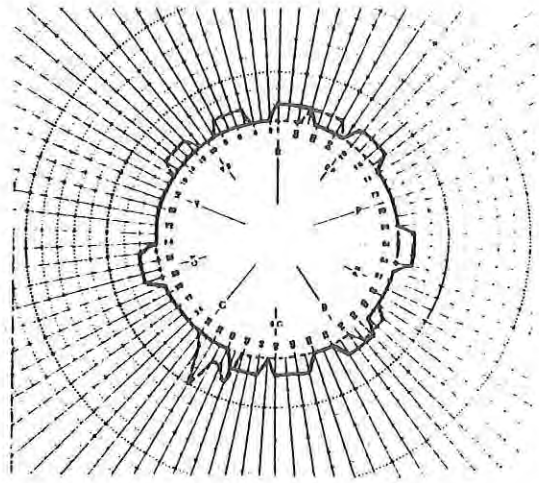

Figure B-2
Specimens of normal, average
discrimination patterns, 2 trials

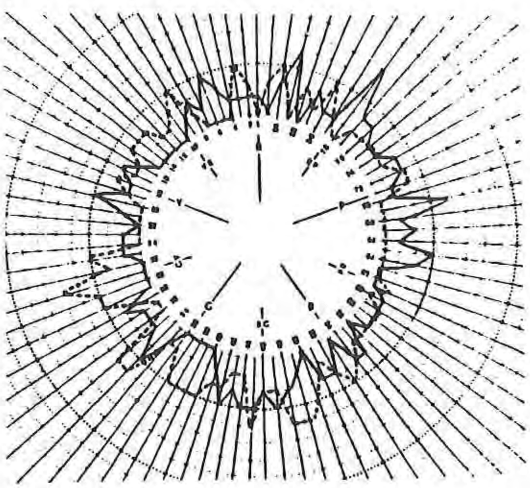

Figure B-3
Specimens of normal, low
discrimination patterns, 2 trials

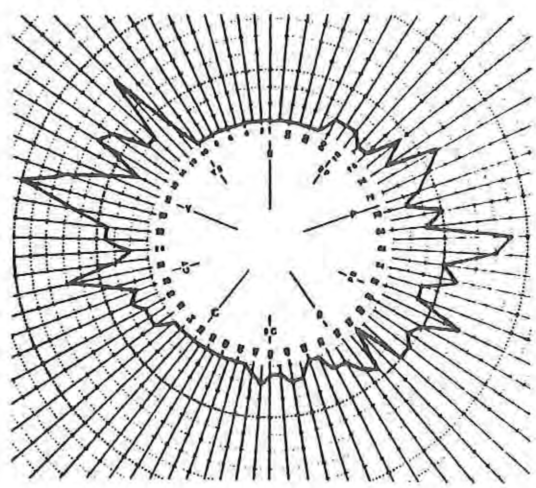

Figure B-4
Specimen of color defective pattern:
protan, average of 2 trials

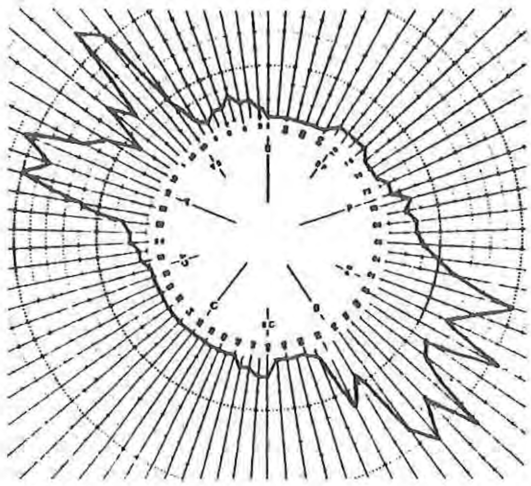

Figure B-5
Specimen of color defective pattern:
deutan, average of 2 trials

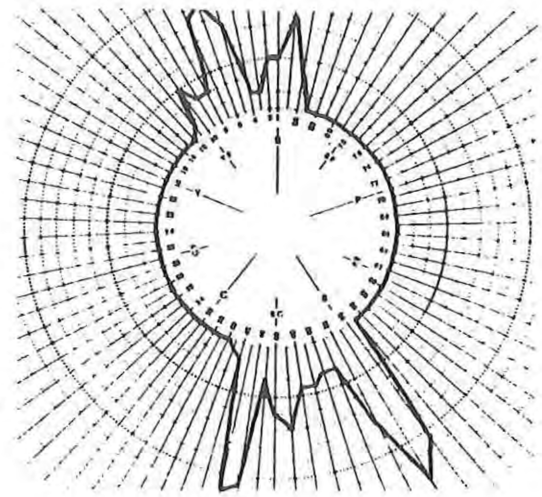

Figure B-6
Specimen of color defective pattern:
tritan, average of 2 trials

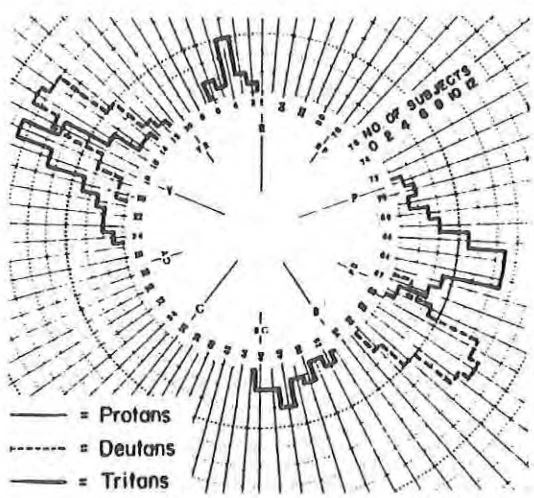

Figure B-7
Distribution of mid-points from 112 tests
on color defective subjects: 50 protans
50 deutans and 12 tritans

APPENDIX C
VEHICLE GAUGES AND DISPLAYS: COMPATIBILITY CHECKLISTS

DRIVER - M60A3

1. INDICATOR PANEL - BATTERY-GENERATOR GAUGE
2. INDICATOR PANEL - FUEL GAUGE
3. INDICATOR PANEL - TRANSMISSION OIL TEMP. LIGHT
4. SPEEDOMETER
5. MASTER CONTROL PANEL - MASTER BATTERY LIGHT

TANK COMMANDER - M60A3

1. STATIONARY INDICATOR
2. MOVING INDICATOR
3. ADPS INDICATOR
4. FSDS INDICATOR
5. HEAT INDICATOR
6. HEP/WP INDICATOR
7. THERMAL CHANNEL
8. PASSIVE SIGHTS

GUNNER - M60A3

1. AZIMUTH INDICATOR
2. ELEVATION SCALE (105 MM GUN)
3. GUNNER CONTROL UNIT - SELF TEST LAMPS
4. GUNNER CONTROL UNIT - MIDDLE PANEL DISPLAYS
5. GUNNER CONTROL UNIT - DATA ENTRY AREAS

GUNNER - M60A3 CONT'D

6. STATIONARY INDICATOR

7. MOVING INDICATOR

8. APDS INDICATOR

9. FSDS INDICATOR

10. HEAT INDICATOR

11. HEP/WP INDICATOR

12. THERMAL CHANNEL

DRIVER - M113A3

1. MAIN CONTROL PANEL - POWER LIGHT

2. MAIN CONTROL PANEL - FUEL GAUGE

3. SPEEDOMETER

4. ENGINE OIL LOW PRESSURE LIGHT

DRIVER - M1A1 (ABRAMS)

1. VEHICLE MASTER POWER LIGHT

2. PARKING/SERVICE BRAKE LIGHTS

3. TURRET POWER LIGHT

4. STARTED LIGHT

5. HI BEAM LIGHT

6. MASTER WARNING LIGHT

7. MASTER CAUTION LIGHT

8. LOW FUEL LEVEL LIGHT

TANK COMMANDER - M1A1 (ABRAMS)

1. VEHICLE MASTER POWER LIGHT
2. AUXILARY HYDRAULIC POWER LIGHT
3. TURRET POWER LIGHT
4. MANUAL LIGHT ON GPS
5. RETICLE

GUNNER - M1A1 ABRAMS

1. DOMELIGHT
2. LIGHTS ON GPS UPPER AND LOWER PANELS
3. TIS PANEL LIGHT
4. POWER LIGHT
5. COMPUTER CONTROL PANEL LIGHTS
6. FIVE DISPLAY WINDOW NUMBERS
7. FIRE CONTROL MODE INDICATOR LIGHTS
8. COAX INDICATOR LIGHT
9. TRIGGER SAFE INDICATOR LIGHT
10. MAIN INDICATOR LIGHT
11. AMMUNITION SELECT GREEN INDICATOR LIGHTS
12. RETICLE

DRIVER - M3 (BRADLEY)

1. MASTER POWER INDICATOR LIGHT
2. ENGINE ACCESSORY INDICATOR LIGHT
3. TURN INDICATOR LIGHTS
4. TURRET POWER INDICATOR LIGHT
5. HIGH BEAM INDICATOR LIGHT
6. RAMP UNLOCKED INDICATOR LIGHT

TANK COMMANDER - M3 (BRADLEY)

1. TURRET POSITION INDICATOR
2. AZIMUTH INDICATOR AND POINTER
3. SLOPE INDICATOR CIRCLES
4. TURRET INDICATOR LIGHT
5. STAB INDICATOR LIGHT
6. RETICLE

GUNNER - M3 (BRADLEY)

1. ARM - SAFE - RESET INDICATOR LIGHT
2. SEAR INDICATOR LIGHT
3. APSS INDICATOR LIGHT
4. APLO INDICATOR LIGHT
5. APHI INDICATOR LIGHT
6. HESS INDICATOR LIGHT
7. HELO INDICATOR LIGHT
8. HEHI INDICATOR LIGHT
9. RETICLE

APPENDIX D
BREAKDOWN OF RESPONSES TO LENS QUESTIONS IN VEHICLE STATIC TESTS

AO3

Ability to do job affected? (N=175)

VEHICLE	JOB	YES	N	%	Comments
Abrams	driver	1	36	3	lens not dark enough
	gunner	9	37	24	frame won't allow you to get close to reticle
	tank commander	2	36	6	can't get close to sight
Bradley	driver	2	22	9	easier to see lights
	gunner	2	22	9	can't get close enough to reticle
	tank commander	2	22	5	slow the soldier down

Colors affected? (N=175)

VEHICLE	JOB	YES	N	%	Comments
Abrams	driver	3	36	8	darker; green to blue; yellow to orange
	gunner	2	37	5	clearer; green to light blue
	tank commander	2	36	6	brighter and clearer; yellow to light green; orange lighter
Bradley	driver	2	22	9	brighter; gauges easier to read
	gunner	-	22	-	
	tank commander	1	22	5	brighter and clearer

AO123(P)

Ability to do job affected? (N=44)

VEHICLE	JOB	YES	N	%	Comments
Abrams	driver	-	4	-	
	gunner	-	4	-	
	tank commander	3	5	60	too dark; reticle problems
Bradley	driver	1	1	100	harder to see gauges clearly
	gunner	4	15	27	too dark; double reticle
	tank commander	6	15	40	too dark; can't fire

Colors affected?
(N=45)

VEHICLE	JOB	YES	N	%	Comments
Abrams	driver	4	4	100	lighter; green to blue, clear, and grey
	gunner	5	5	100	green to blue and clear; can't red; can't distinguish red-green; white to purple
	tank commander	4	5	80	green to blue; white to purple; reticles darker
Bradley	driver	1	1	100	darker; difficult to see needle-white
	gunner	6	15	40	arm sv looks orange; sky looks violet; red darker; white to purple
	tank commander	7	15	47	everything purple; red to blue on slope indicator; red to brown; ground looks yellow

A012 (N=174)

Ability to do job affected?

VEHICLE	JOB	YES	N	%	Comments
Abrams	driver	3	36	8	too dark; harder to see gauges
	gunner	12	36	33	can't get close to reticle; too dark
	tank commander	8	36	22	can't see reticle; too dark
Bradley	driver	1	22	5	harder to see gauges
	gunner	2	22	9	too dark; can't get close
	tank commander	4	22	18	too dark; can't see red; hard to see words on indicators

Colors affected?
(N=174)

VEHICLE	JOB	YES	N	%	Comments
Abrams	driver	13	36	36	darker; green to blue; orange to yellow-red; green and red dimmer; yellow darker
	gunner	18	36	50	green to blue; darker; red darker; dimmer; orange to yellow; yellow to white; outside green to black and light to purple
	tank commander	12	36	33	darker; dimmer; can't see reticle; green to blue; yellow to red; white to orange; brighter
Bradley	driver	10	22	45	all colors dimmer; all darker, esp. green, colors deeper and easier to see but less bright
	gunner	9	22	41	darker; dimmer; no background for reticle; orange to yellow; red to orange; outside blue to red
	tank commander	4	22	18	darker; no red; green to brown

A023

Ability to do job affected?
(N=178)

VEHICLE	JOB	YES	N	%	Comments
Abrams	driver	4	38	11	too dark; tough to read gauges; makes things brighter
	gunner	19	38	50	reticle too dim to see; can't get close because of frame
	tank commander	14	36	39	can't see reticle; can't get close

VEHICLE	JOB	YES	N	%	Comments
Bradley	driver	5	22	23	everything brighter; gauges difficult to see
	gunner	5	22	23	frame a problem; can't see reticle
	tank commander	6	22	27	can't see reticle, azimuth or words on indicator lights

Colors affected?
(N=178)

VEHICLE	JOB	YES	N	%	Comments
Abrams	driver	22	38	58	yellow dulled; orange to yellow; brown to green; green to blue
	gunner	27	38	71	reticle faint; red dimmer or disappears; white to green or yellow; yellow to white
	tank commander	18	36	50	lighter; orange to yellow; white to yellow or green; red faded; green to blue
Bradley	driver	11	22	50	darker; brighter; blue to green; red panel lights faded; green brighter; yellow to green
	gunner	14	22	64	yellow to green; orange panel lights to green; all colors green except red; all colors brown
	tank commander	14	22	64	orange to yellow; everything to green except red; red too dark- almost black

A0123(B)

Ability to do job affected?
(N=131)

VEHICLE	JOB	YES	N	%	Comments
Abrams	driver	5	33	15	hard to read panel lights, instruments - too dark
	gunner	11	32	34	can't get close to reticle - can't get accurate shot; can't pick out targets
	tank commander	13	31	42	can't see reticle; can't get close to sight; panel lights too dark
Bradley	driver	2	21	10	difficult to read gauges and see green lights
	gunner	1	7	14	impairs vision slightly
	tank commander	1	7	14	can't see indicator lights

Colors affected?
(N=131)

VEHICLE	JOB	YES	N	%	Comments
Abrams	driver	9	33	27	darker; green to blue; red to orange; orange to yellow
	gunner	14	32	43	darker; green to blue; red to orange; orange to white
	tank commander	12	31	39	darker; can't see reticle; green to blue; lighter; reticle is blue
Bradley	driver	8	21	38	red darker; dimmer; green brighter
	gunner	5	7	71	darker; reticle looks pink; orange to white; terrain looks lighter
	tank commander	2	7	29	darker

DISTRIBUTION LIST

	Copies
Commander	
U.S. Army Natick RD&E Center	
Technical Library	4
Behavioral Sciences Division, Human Factors Branch	
ATTN: STRNC-YBH	194
Individual Protection Directorate	
ATTN: STRNC-ICAA	50
Administrator, Defense Technical Information Center Cameron Station Alexandria Virginia 22304-6145	2